Recent Results on QCD from DØ

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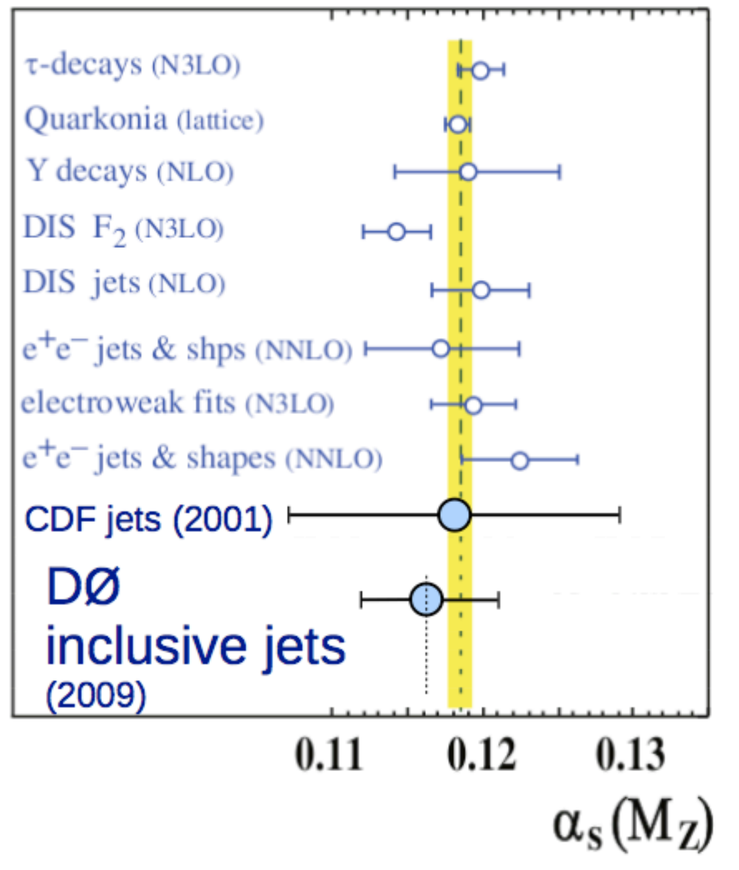
CERN Seminar

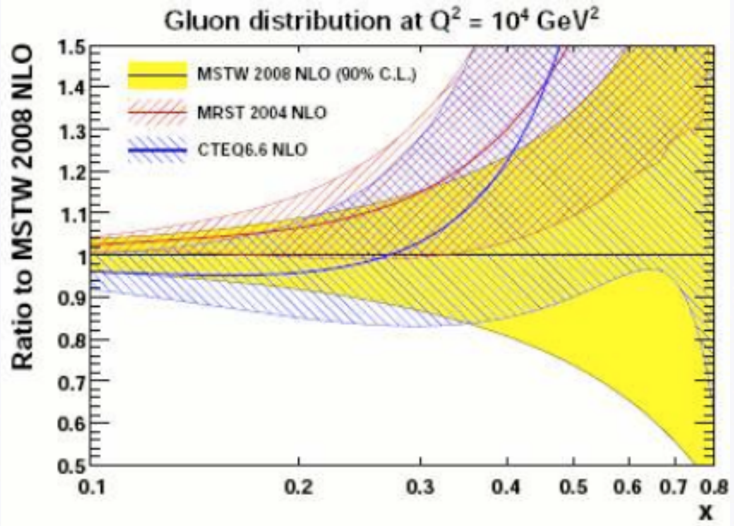


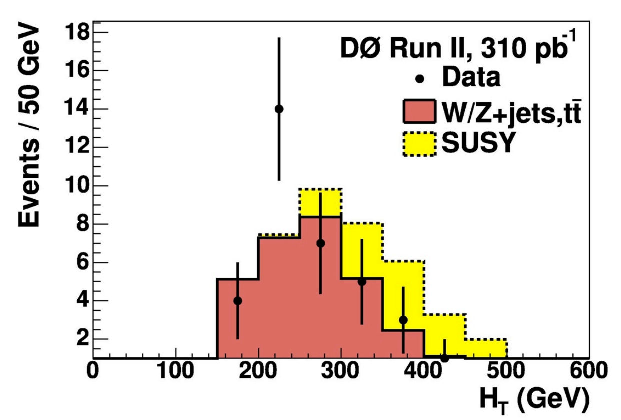
Outline

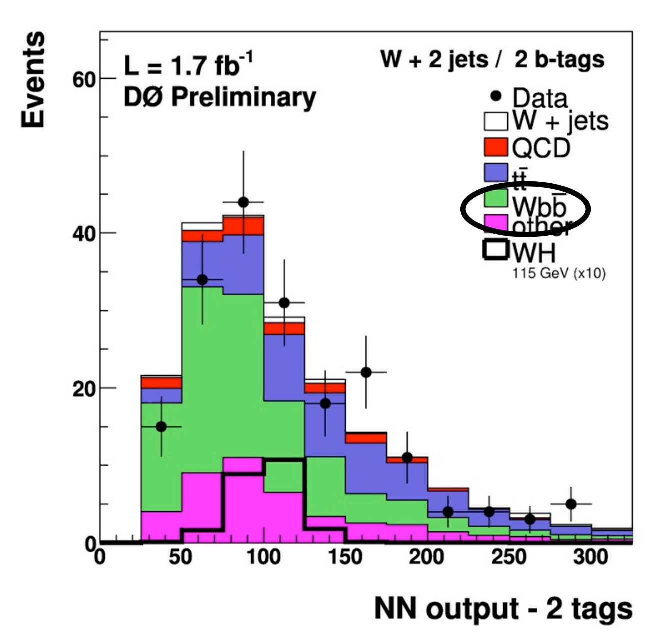
- Motivation
- Apparatus: Tevatron and D0
- QCD Measurements in pure Hadronic Final States
  - Inclusive Jets and α_s extraction
  - Three-jet cross sections and 3/2 jet ratios
- QCD Measurements involving Vector Bosons + Jets
- QCD Measurements of MinBias, Multiple Parton and Elastic Interactions
- Summary and Outlook

Three Main Motivations

- Test perturbative QCD
  - Explore new kinematic regimes
  - provide important inputs to PDFs
- Search for New Physics
  - resonances can show up in jets too!
  - use SM as a guide
- Measure important backgrounds to New Physics
  - N(N)LO predictions not available for many processes of interest, particularly those with large jet multiplicities and heavy flavor components => data measurements crucial
  - New Physics share signatures with irreducible backgrounds that are currently being pinned down.
  - Interplay between fragmentation models, tunes, PDFs and scale choices needs to be understood to model SM backgrounds







Analysis Subjects

Jets

- pQCD tests
- inputs to global PDF fits
- extract α_s

W/Z/γ^* + light/heavy jets

- pQCD tests
- test and tune MC models
- Heavy flavor production is sensitive to b, c quark PDFs

Diffraction & Elastic Scattering

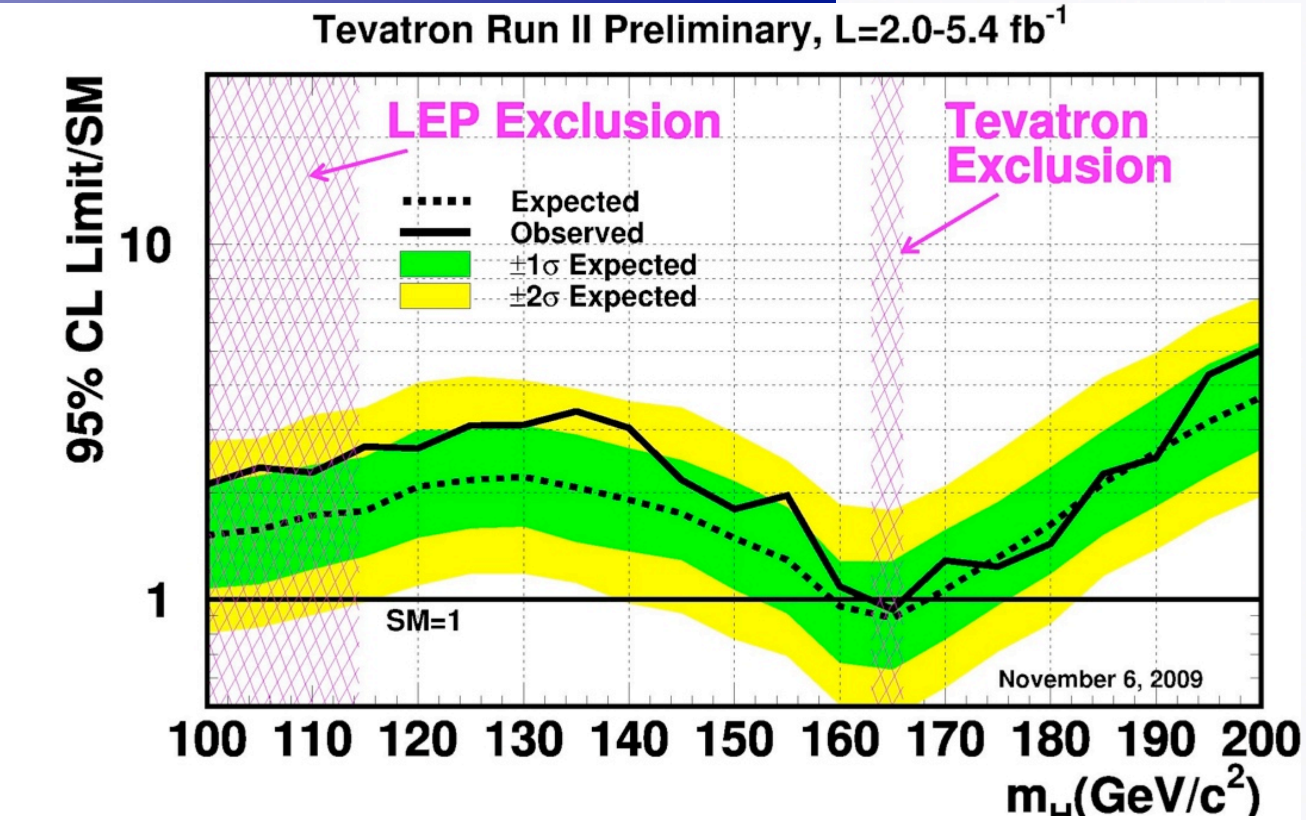
- total elastic scattering cross section
- measurements with FPD

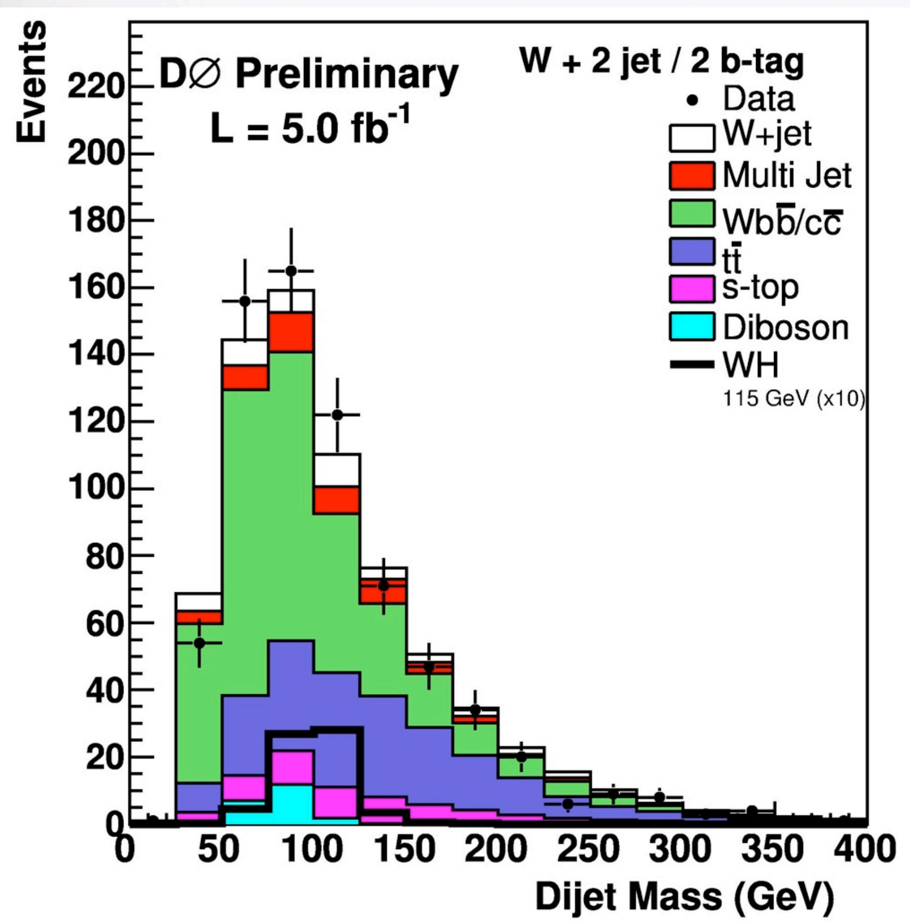
Soft, MinBias, MPI Physics

- soft and hard scales
- universal backgrounds many analyses don't think much about

Higgs

- SM Higgs Search driving extension of Tevatron run
- Sensitivity improves primarily by adding data
- Dominant systematics are from V+jets cross sections





D0: Single Tag (ST) $ZH \to \ell\ell b\bar{b}$ analysis relative uncertainties (%)

Contribution	WZ/ZZ	Zbb/Zcc	Zjj	$t\bar{t}$	Multijet	ZH
Luminosity	6	6	6	6	0	6
EM ID/Reco eff.	2	2	2	2	0	2
Muon ID/Reco eff.	2	2	2	2	0	2
Jet ID/Reco eff.	2	2	2	2	0	2
Jet Energy Scale (shape dep.)	5	5	5	5	0	5
b-tagging/taggability	5	5	5	5	0	5
Cross Section	6	30	6	10	0	6
MC modeling	0	4	4	0	0	0
Instrumental-ZH	0	0	0	0	50	0

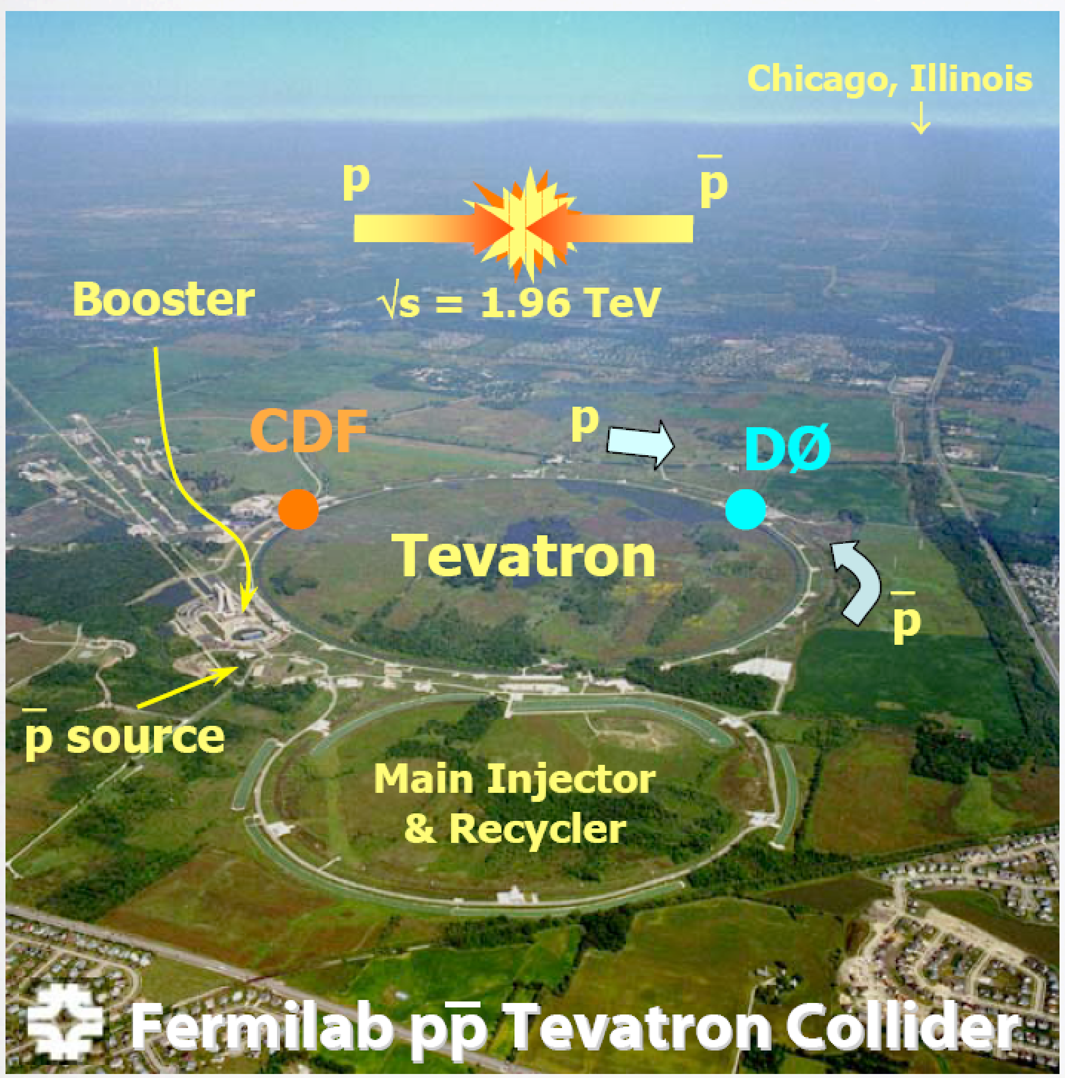
D0: Double Tag (DT) $WH \to \ell\nu b\bar{b}$ analysis relative uncertainties (%)

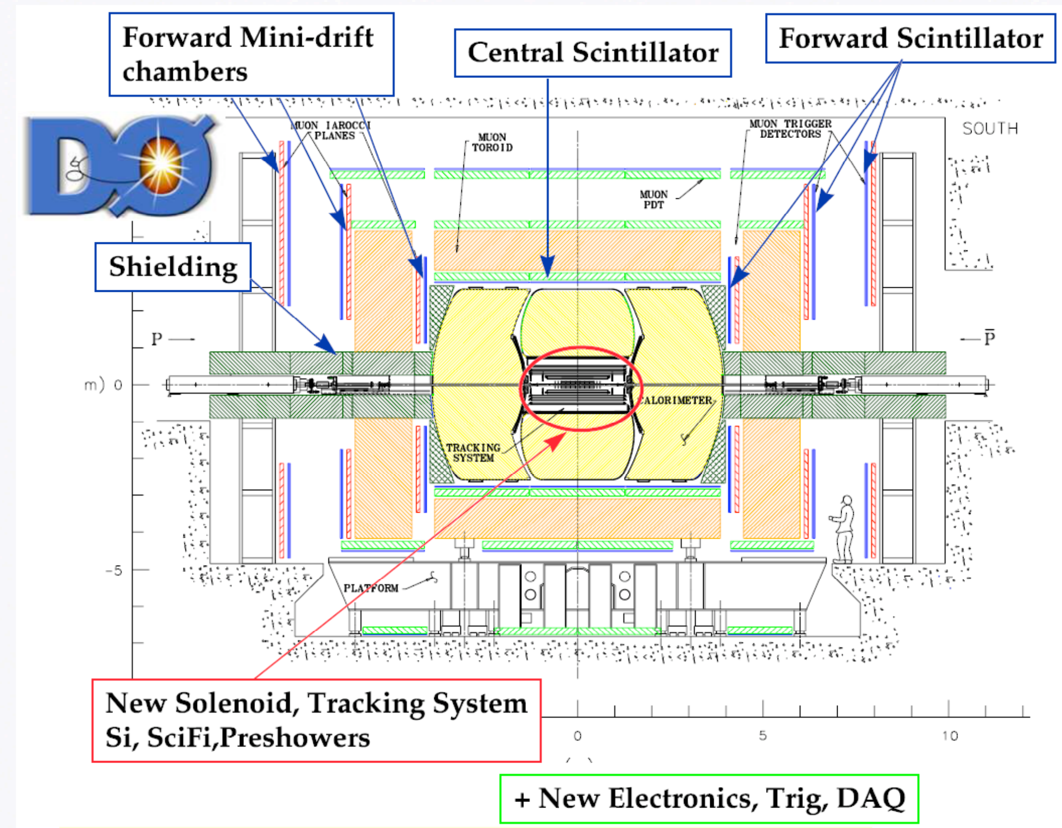
Contribution	WZ/WW	Wbb/Wcc	Wjj/Wcj	$t\bar{t}$	single top	Multijet	WH
Luminosity	6	6	6	6	6	0	6
Trigger eff.	2–5	2–5	2–5	2–5	2–5	0	2–5
EM ID/Reco eff./resol.	3	3	3	3	3	0	3
Muon ID/Reco eff./resol.	4.1	4.1	4.1	4.1	4.1	0	4.1
Jet ID/Reco eff.	2	2	2	2	2	0	2
Jet Energy Scale	3	3	3	3	3	0	3
Jet mult./frag./modeling	3.5	3.5	3.5	3.5	3.5	0	3.5
b-tagging/taggability	6	6	20	6	6	0	6
Cross Section	6	9	9	10	10	0	6
Heavy-Flavor K-factor	0	20	0	0	0	0	0
Instrumental-WH	0	0	0	0	0	26	0

DØ Experiment

Tevatron and DØ

- Tevatron - energy frontier accelerator for nearly 2 decades
  - 396 ns. bunch spacing
  - collisions at $\sqrt{s}$ = 1.96 TeV
  - scheduled to run through 2011

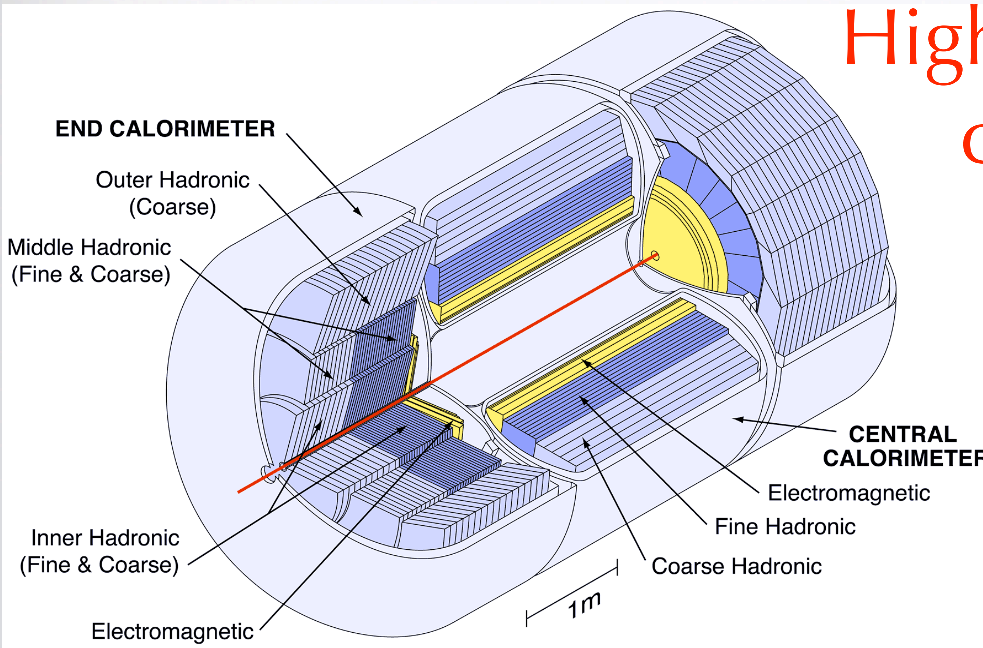




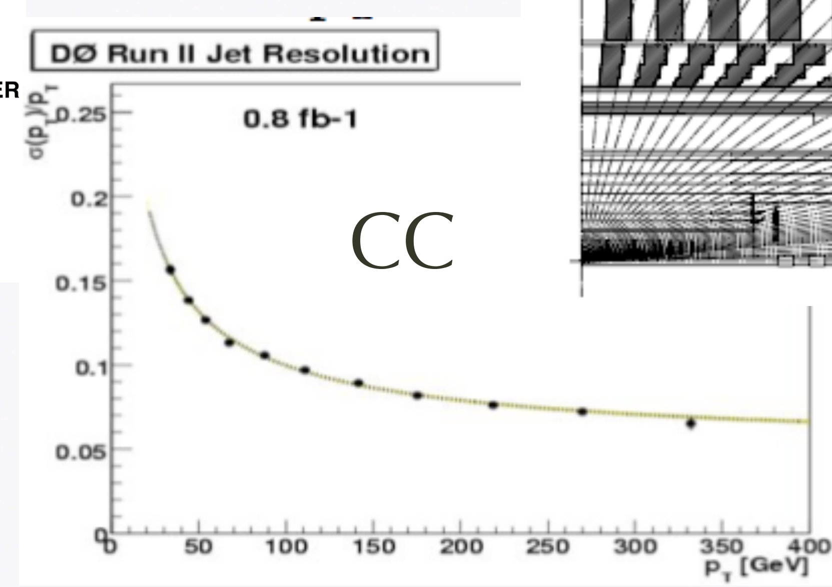
- DØ - Liquid Argon and Uranium Scintillator sampling calorimeter
- Silicon Microstrip (upgraded for Run2b) and Fiber tracking
- Good muon coverage $|\eta| < 2$
- 2T magnetic field

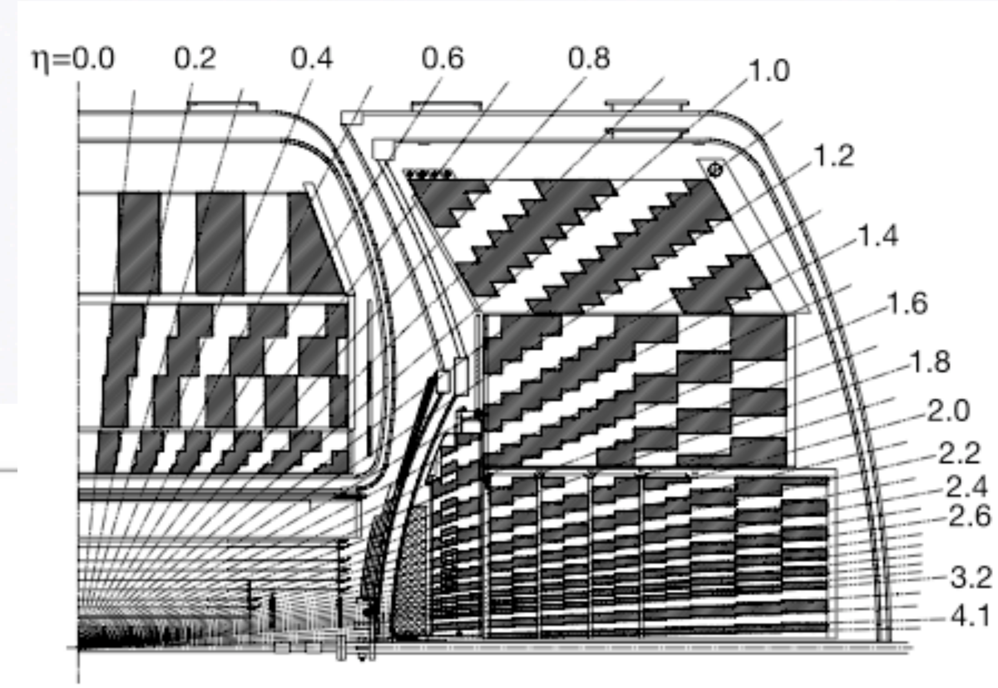
$\eta = -\ln(\tan\theta/2)$

DØ Detector Highlights



High-performance calorimeter



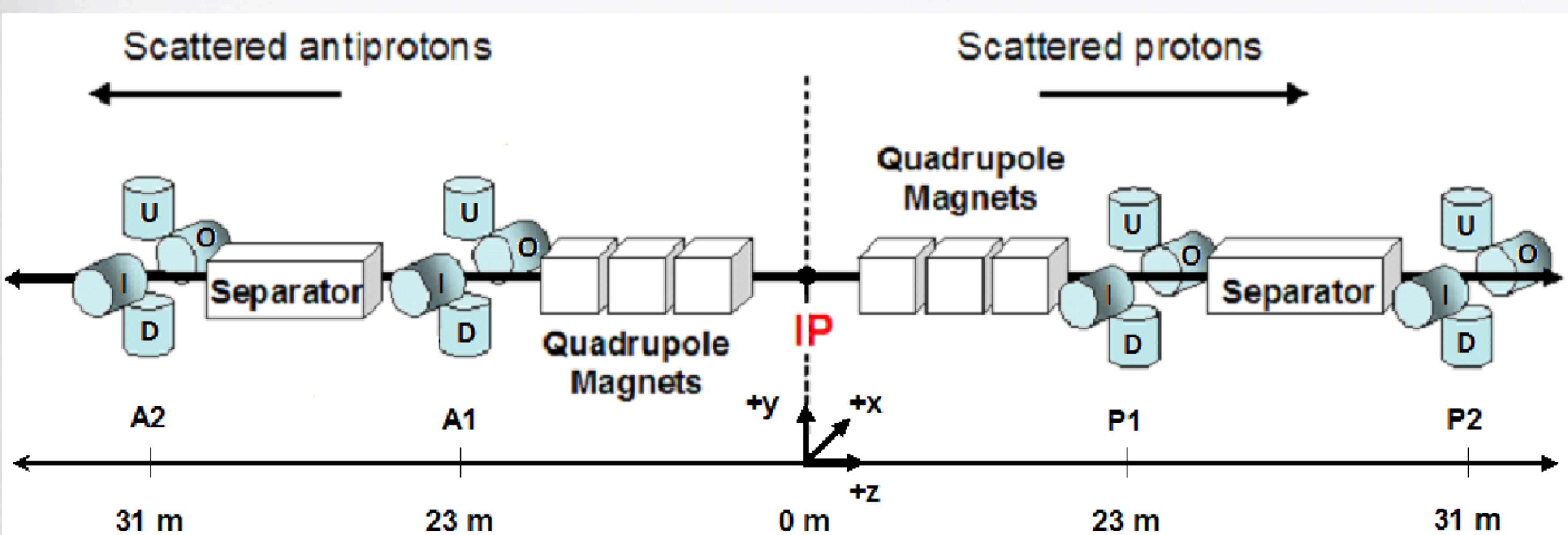


Calorimeter resolutions:
EM: .17/√E, HAD: .45/√E
→ Jet resolutions: 19-6%
in the central calorimeter

Hermetic, $|\eta|<4.2$

No serious degradation yet observed

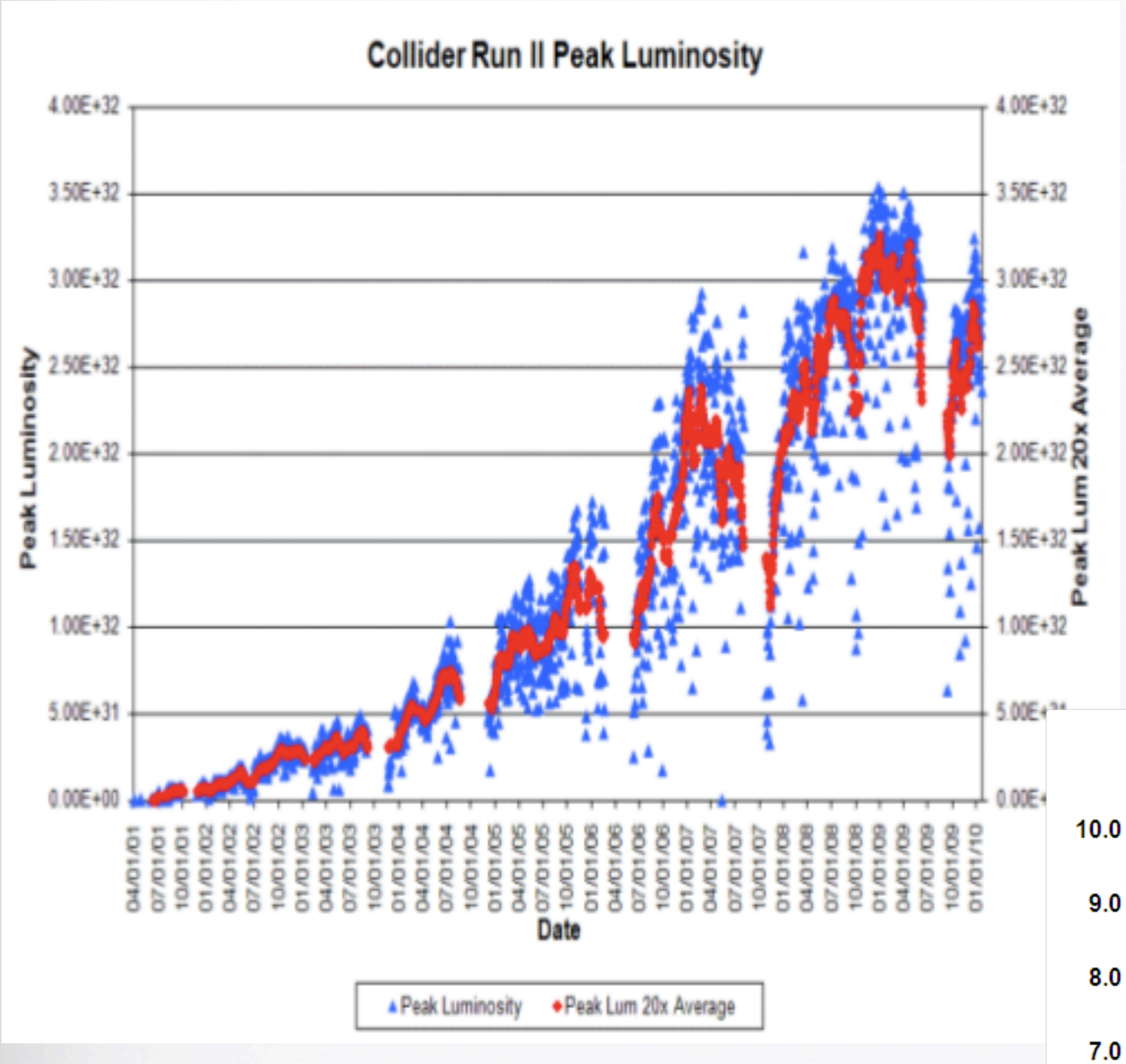
Forward Proton Detector (FPD)

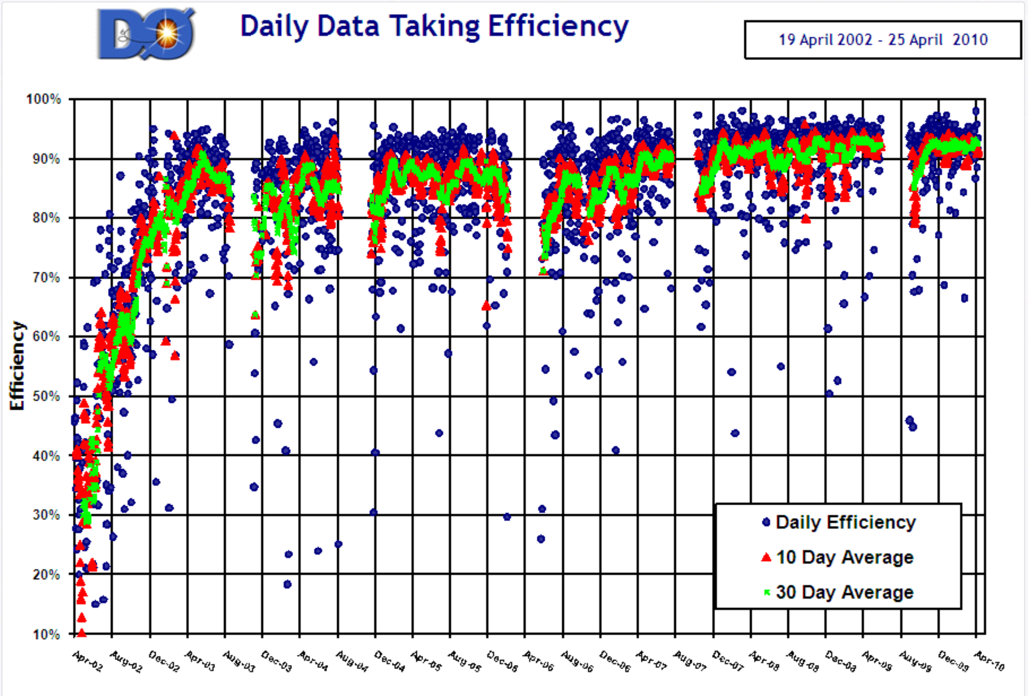


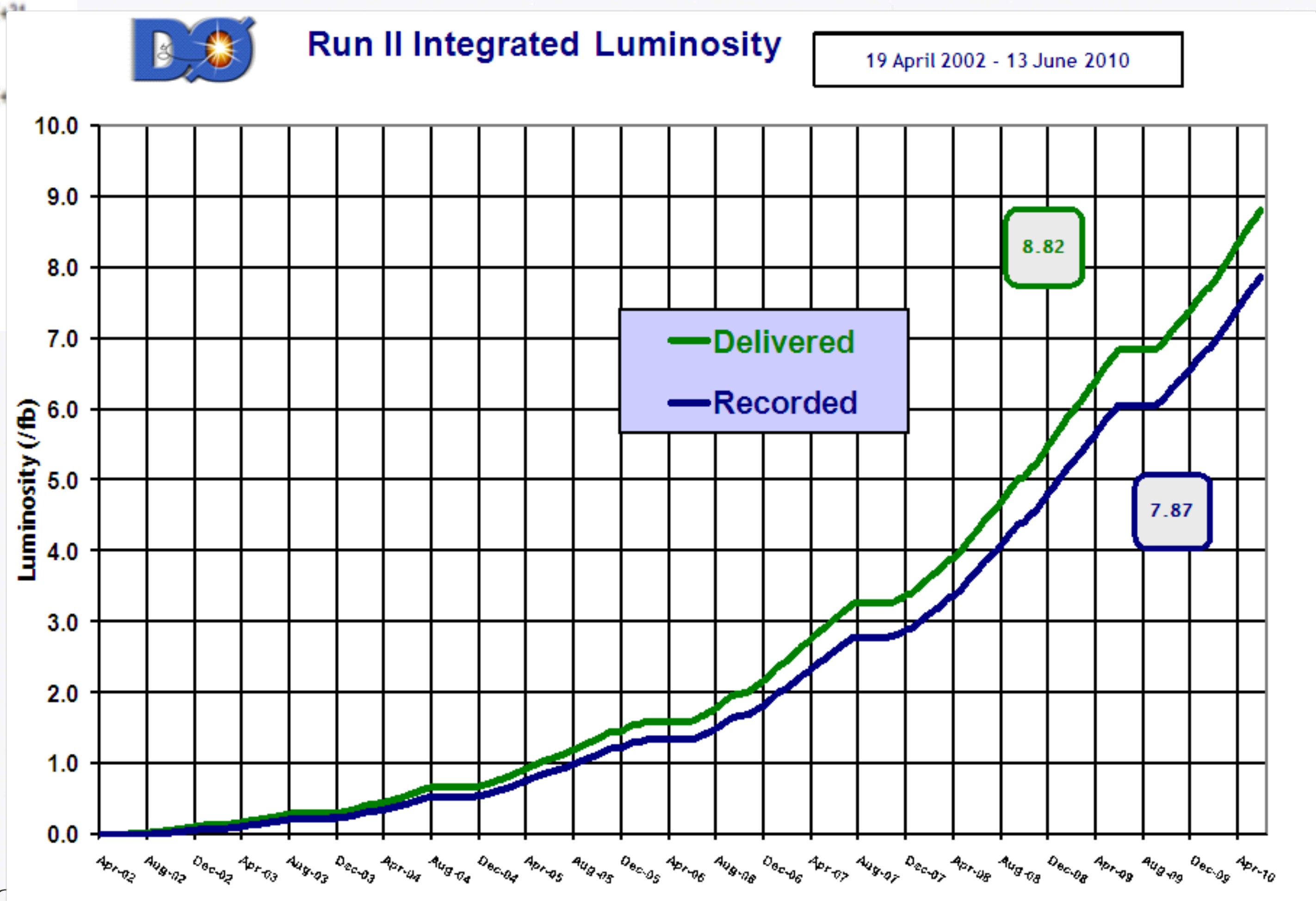
- 8 quadrupole spectrometers per side
- 2 detectors per side
- scintillating fiber hits for track reconstruction
- reconstruct $t = -(p_i-p_f)^2$

$|t| \geq 0.8$ GeV^2

Tevatron and D0 Performance





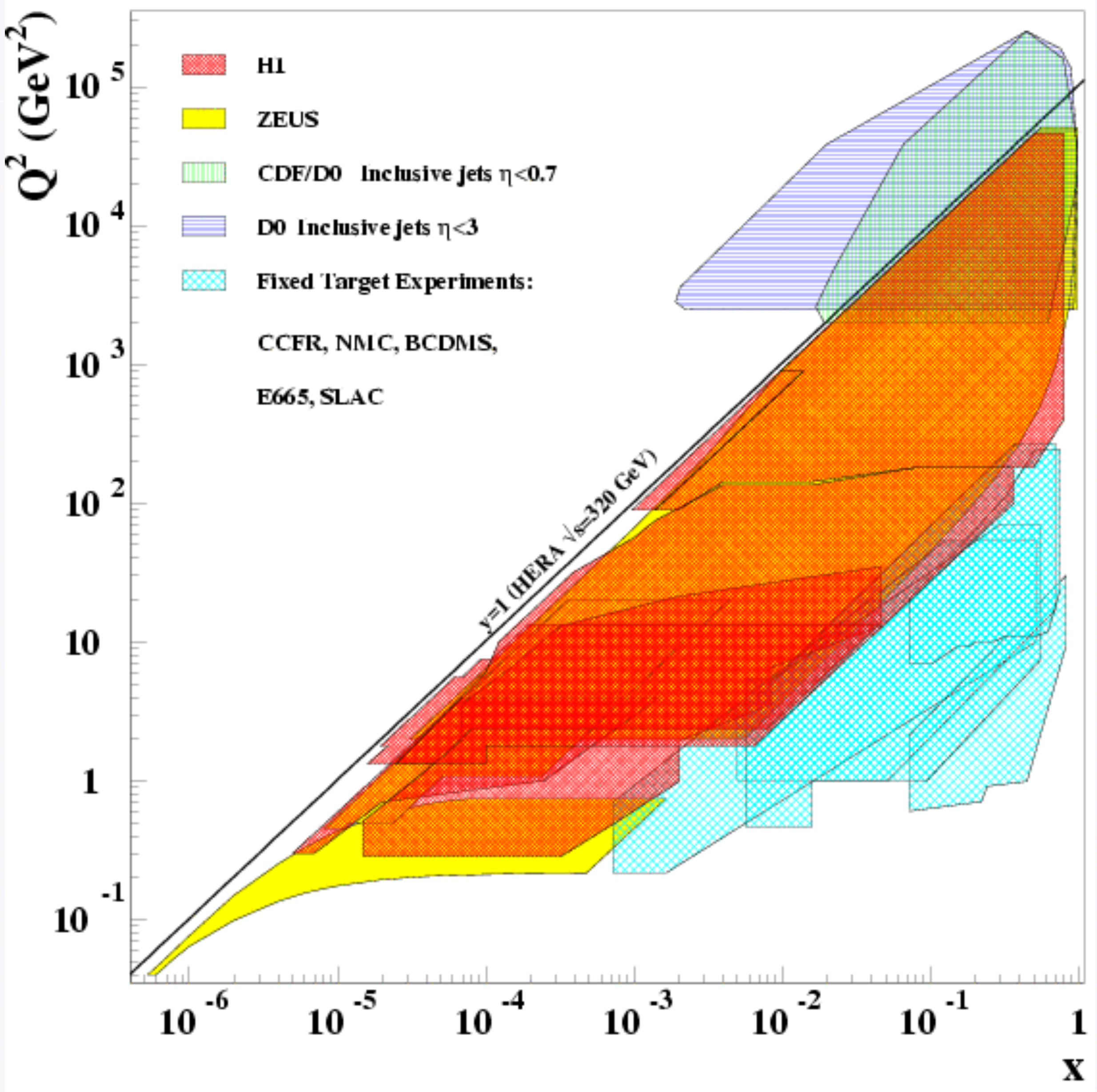


- peak inst. luminosities have recently reached 4E32
- data taking efficiency regularly >90%
- add an $1 fb^{-1}$ every ~4 months of continuous running

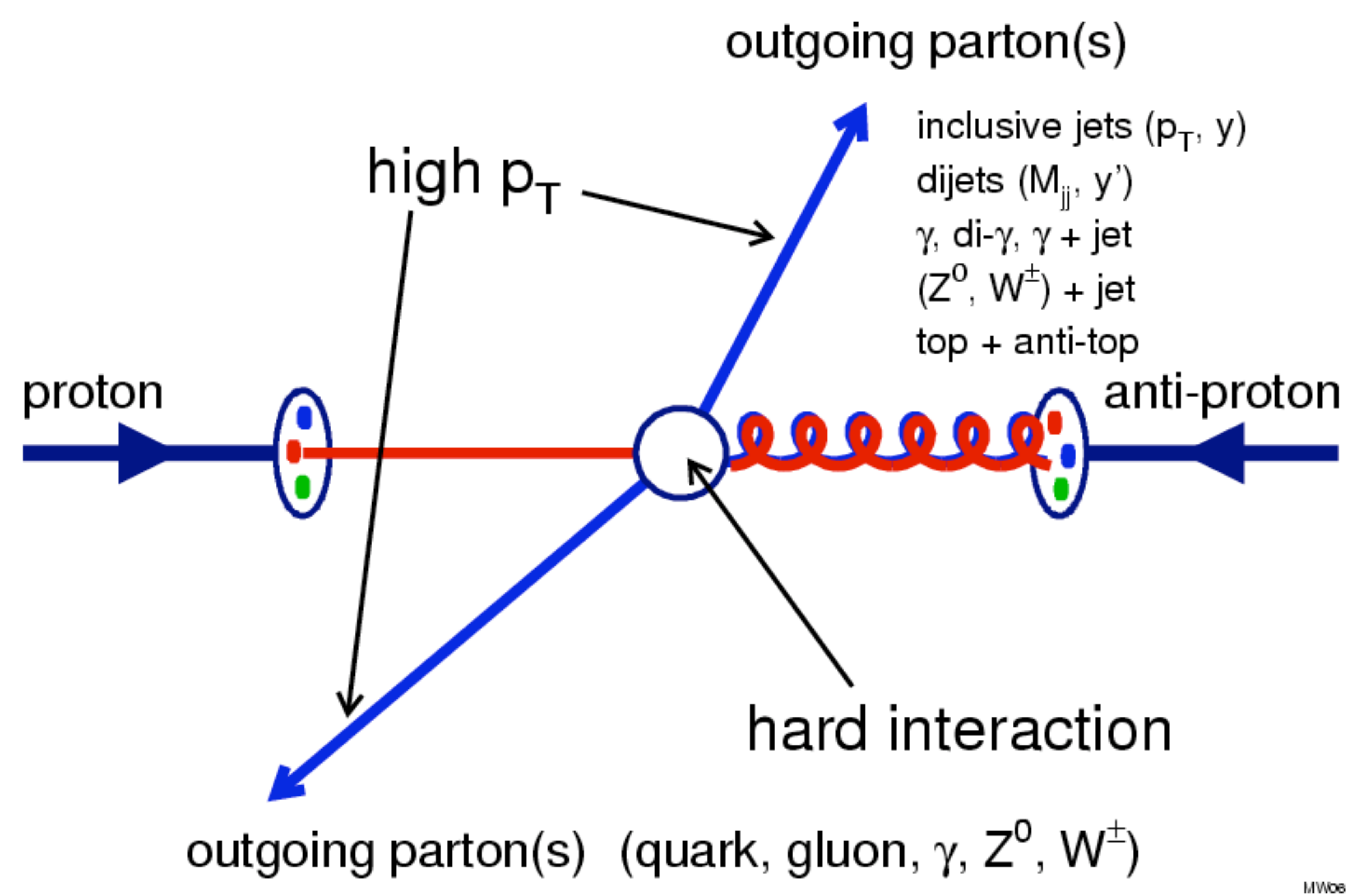
Hadronic Final States

Hard QCD Processes

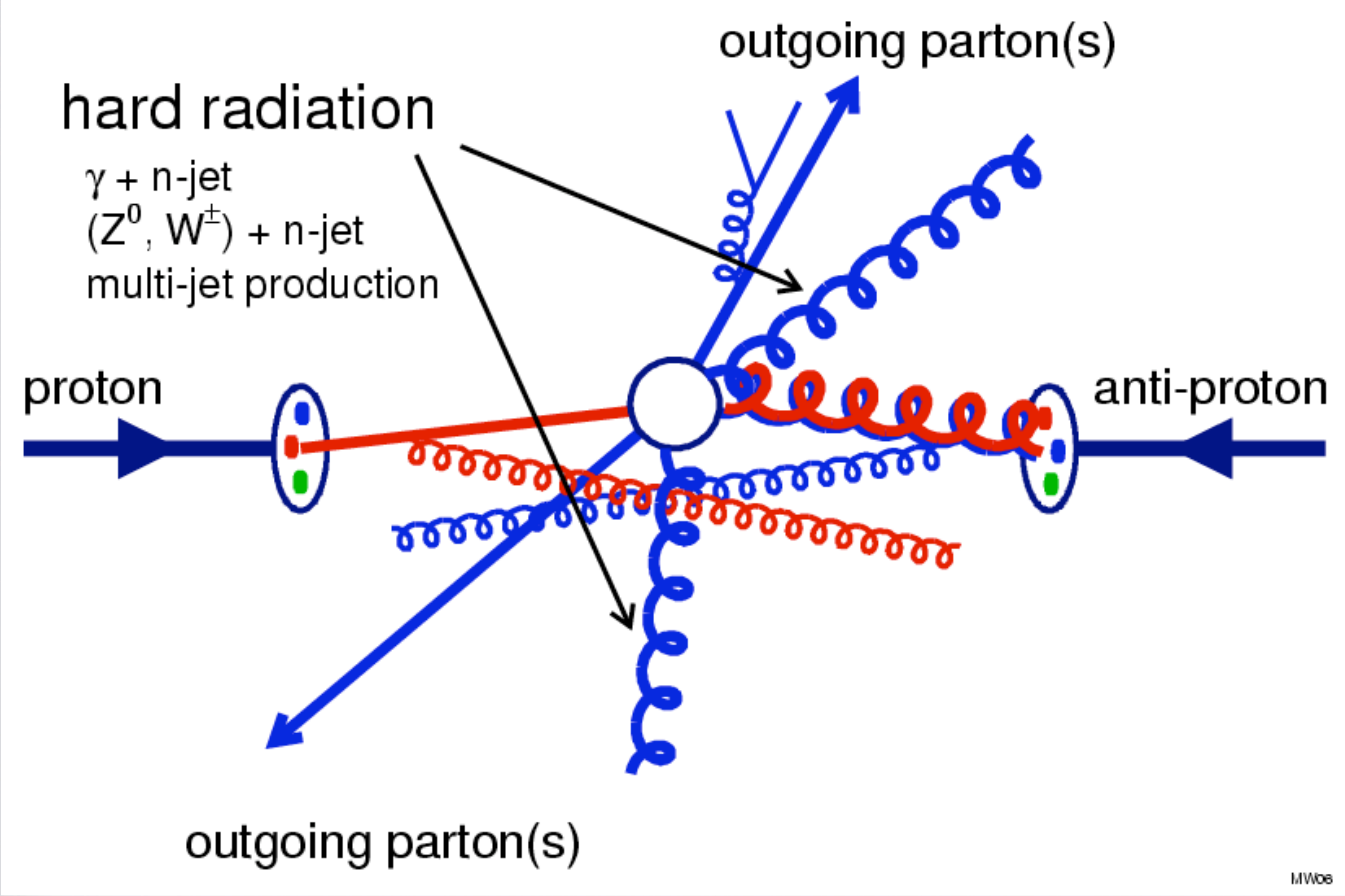
- Tevatron extends kinematic reach to broader x values at high Q^2
- Hard partonic scattering
- Sensitive to strong coupling constant α_s
- Parton density functions (PDFs)
  - unique sensitivity to high-x gluon
- Dynamics of interaction test
  - validity of approximations, e.g NLO pQCD
  - for new physical phenomena



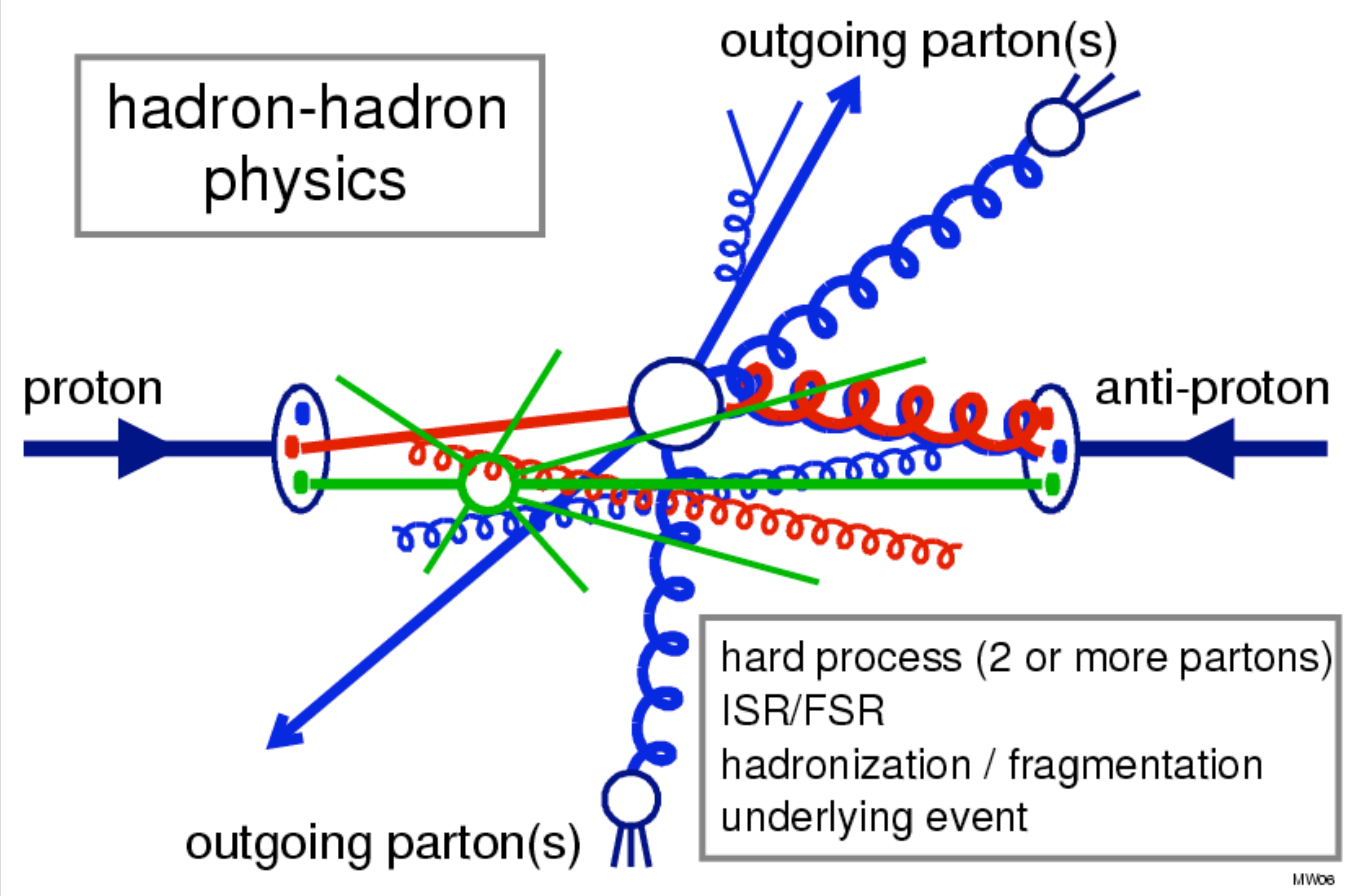
p-$\bar{p}$ collisions



p-p̄ collisions



p-p̄ collisions



Tools of the trade

- Jet Finder: D0 RunII Midpoint Cone Algorithm
- Jet calibration: Jet Energy Scale (JES)
- Heavy-flavor jet identification
- Data are corrected to particle level
  - Acceptance and Efficiencies
- Particle level measurements are compared to NLO theory
- NLO theory is corrected to particle level using parton shower MC

Jet Finder

D0 RunII Midpoint Cone Algorithm

"particle" = {experiment: calorimeter towers / MC: stable particles / pQCD: partons}

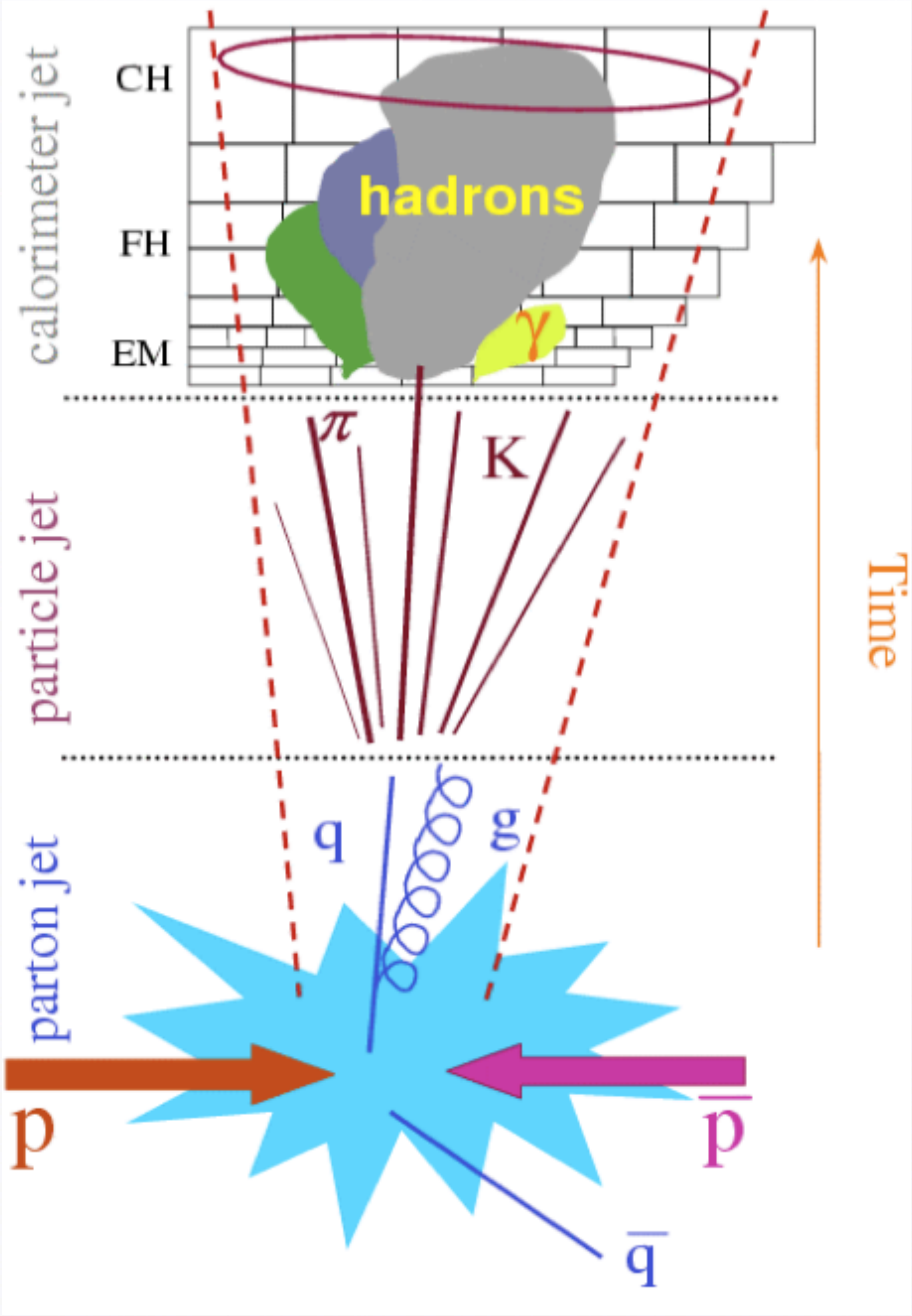
three parameters: $R_{cone} = 0.5$ or 0.7, $p_{T\,\mathrm{min}} = 8$ GeV, overlap fraction $f = 50\%$

- Use all particles as **seeds**
  — make cone of radius $\Delta R = \sqrt{(\Delta y^2 + \Delta\phi^2)} < R_{\mathrm{cone}}$ around seed direction
  — proto jet: add particles within cone in the "E-scheme" (adding four-vectors)
  — iterate until stable solution is found with: cone axis = jet-axis
- Use all **midpoints** between pairs of jets as **additional seeds** $\Longrightarrow$ infrared safety!!!
  — (repeat procedure as described above)

- Take all solutions from the first two steps:
  — remove identical solutions
  — remove proto-jets with $p_{T\,\mathrm{jet}} < p_{T\,\mathrm{min}}$
- Look for jets with **overlapping cones**:
  — merge jets, if more than a fraction f of $p_{T\,\mathrm{jet}}$ is contained in the overlap region
  — otherwise split jets: assign the particles in the overlap region to the nearest jet
  ($\rightarrow$ and recompute jet-axes)

Jet ID Optimization

- Vertex Confirmation: requires that the jet is associated with the primary vertex
  - require minimum number of tracks point to primary vertex
  - put a minimum requirement on the charged particle content of the jet
- Pro: reduces the minbias jet contamination at low p_T
- Con: not usable in far forward region where tracking is poor

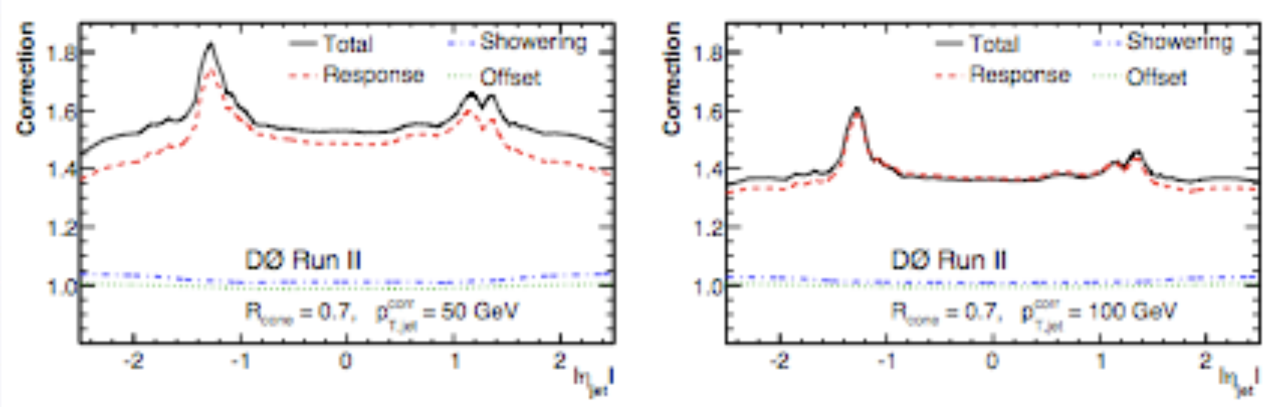


JES Calibration

Corrects jet energy from calorimeter measurement to particle energy

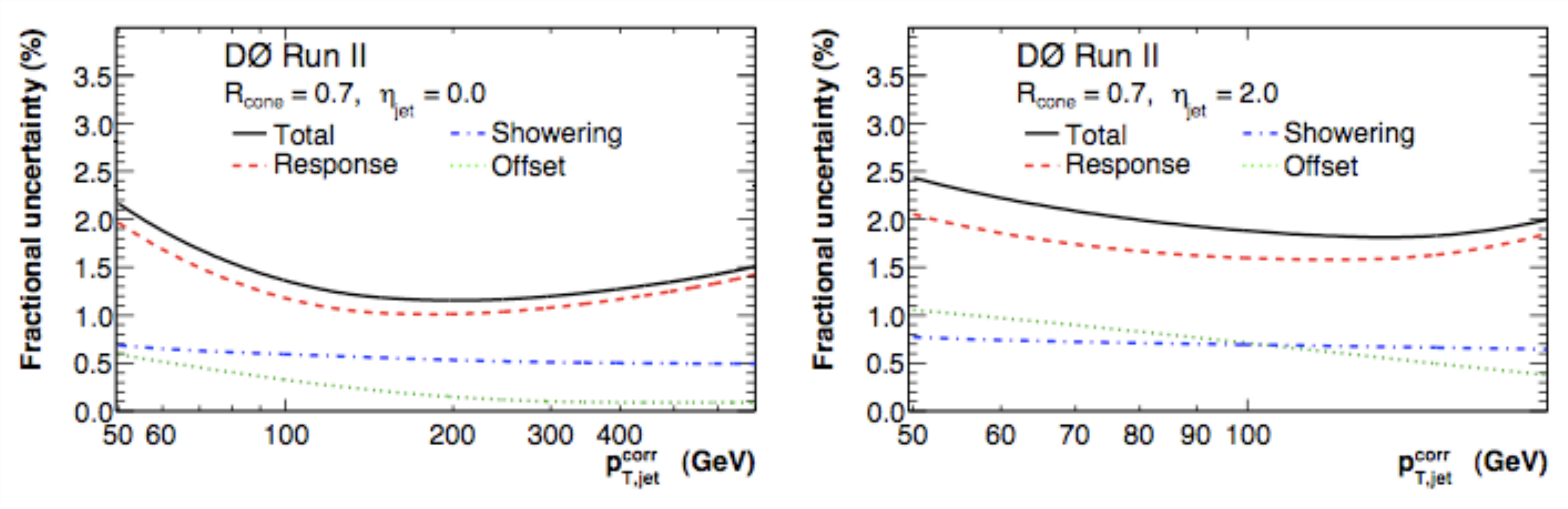
$$E_{\text{particle}} = \frac{E_{\text{cal}} - O}{R \cdot S}$$

O: offset energy
R: calorimeter response
S: detector showering

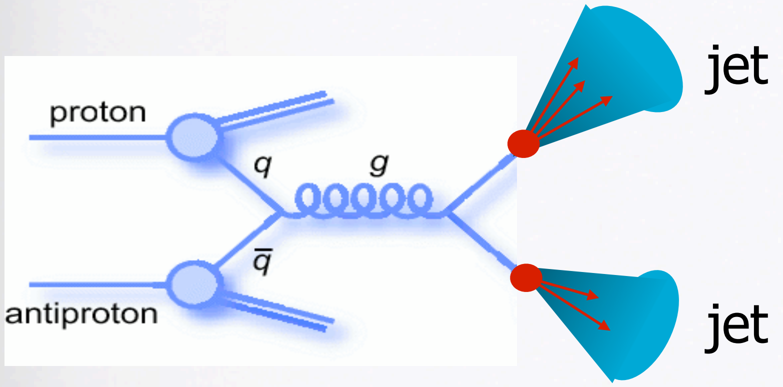


- Offset energy includes
  - electronics noise
  - calorimeter noise from uranium decays
  - pileup from previous bunch crossings
  - energy from multiple collisions during one bunch crossing
- Response R gives average fraction of measured calorimeter energy for the particles inside the particle jet cone: determined from γ+jet events
- Showering S is the net flow of energy in and out of the jet cone due to detector effects

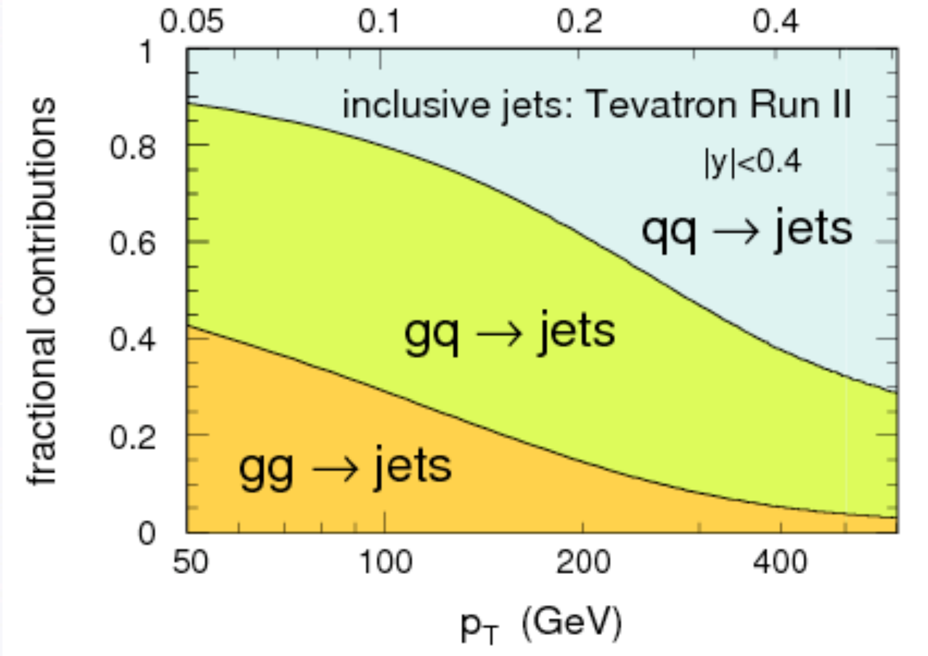
JES Fractional Uncertainties: 1.2-2.5%



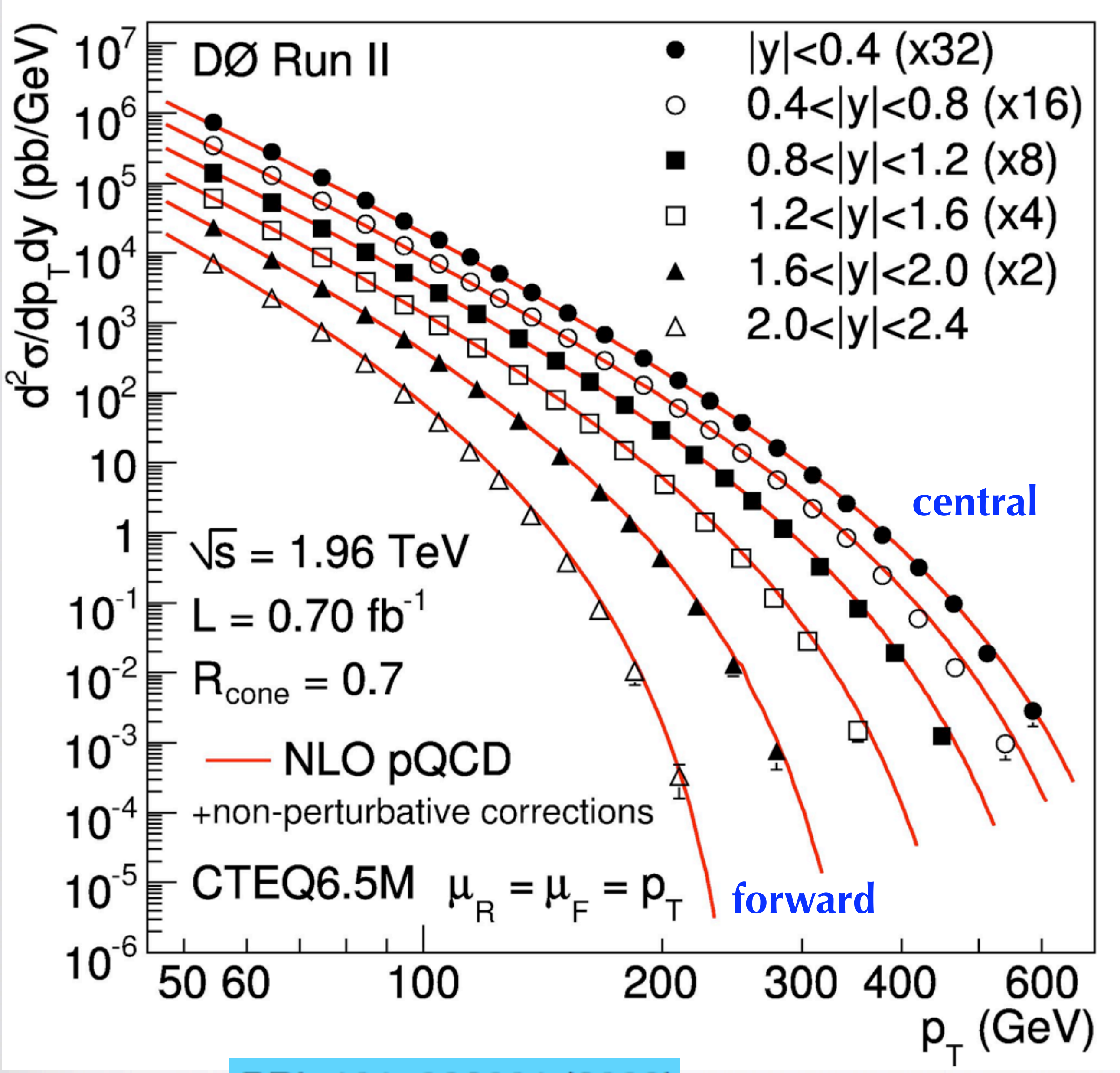
Inclusive Jets



Sensitive to gluon content of the proton



NLO theory is accurate to ~10%
(in the absence of new physics)



PRL 101, 062001 (2008)

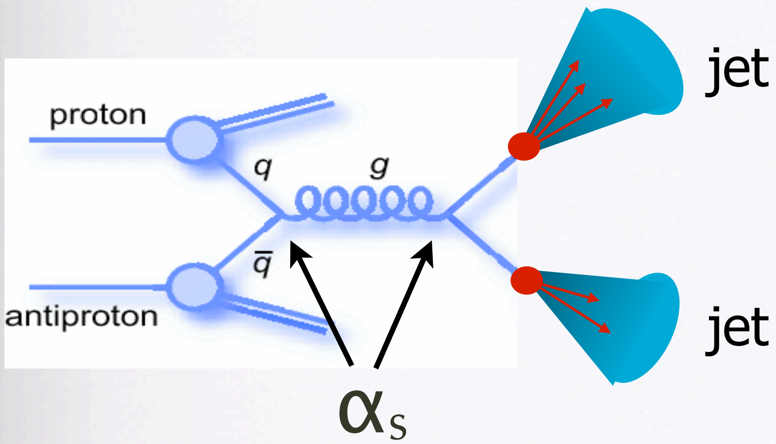
steeply falling p_T spectrum:

- 1% error in jet energy calibration
- 5-10% (10-25%) error in central (forward) x-section

benefit from:

- high luminosity in Run II
- increased Run II cm energy → high p_T
- hard work on jet energy calibration

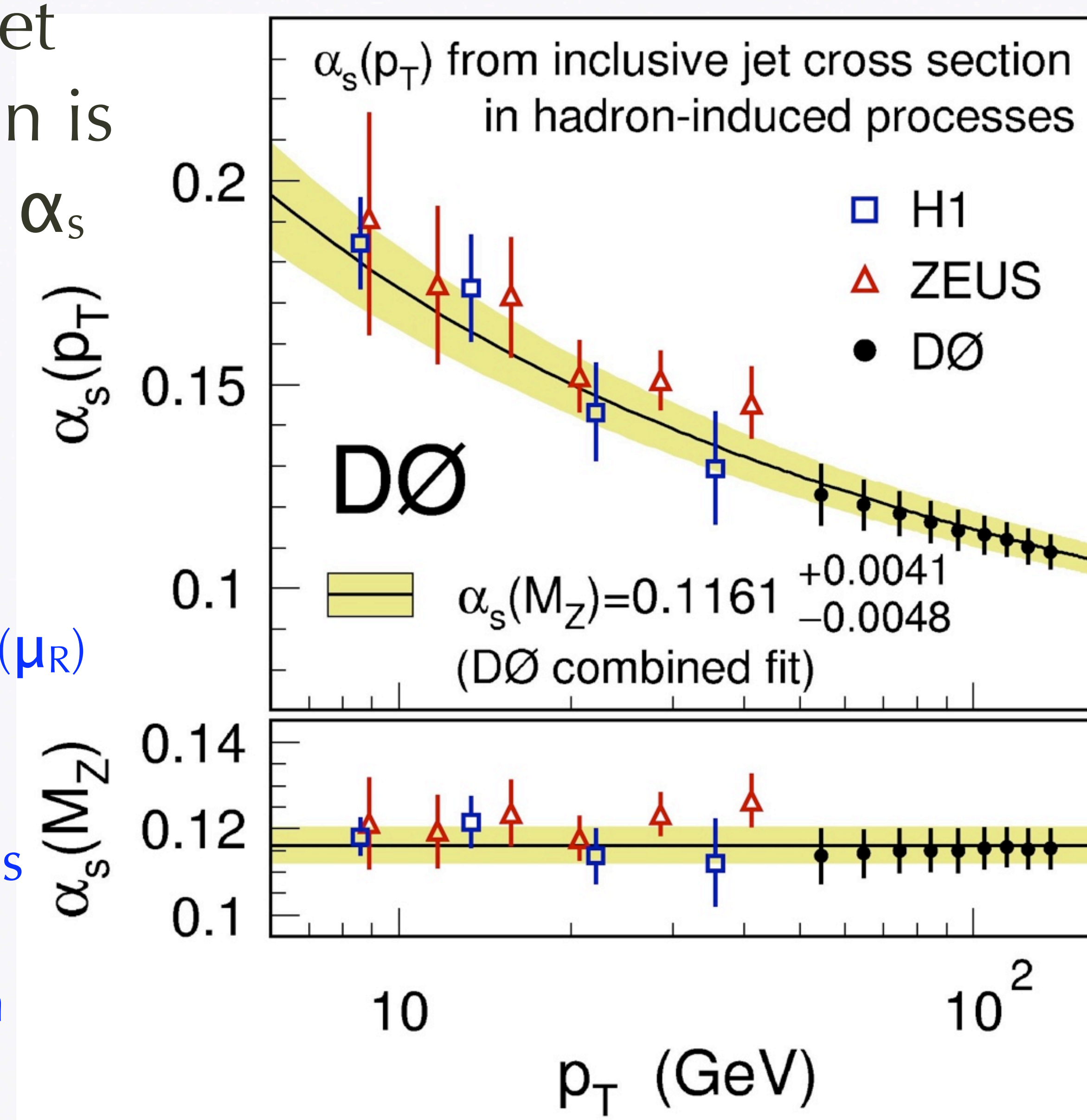
α_s extraction



Inclusive Jet Cross Section is sensitive to α_s

$$\sigma_{\text{pert}}(\alpha_s) = \left(\sum_n \alpha_s^n c_n\right) \otimes f_1(\alpha_s) \otimes f_2(\alpha_s)$$

The coupling strength, α_s, is scale dependent: $\alpha_s(\mu_R)$
Renormalization Group Equation predicts μ_R-dependence
Extract α_s from 22 (out of 110) inclusive jet cross section data points at $50<p_T<145$ GeV
→ Exclude data points with large influence on PDF set

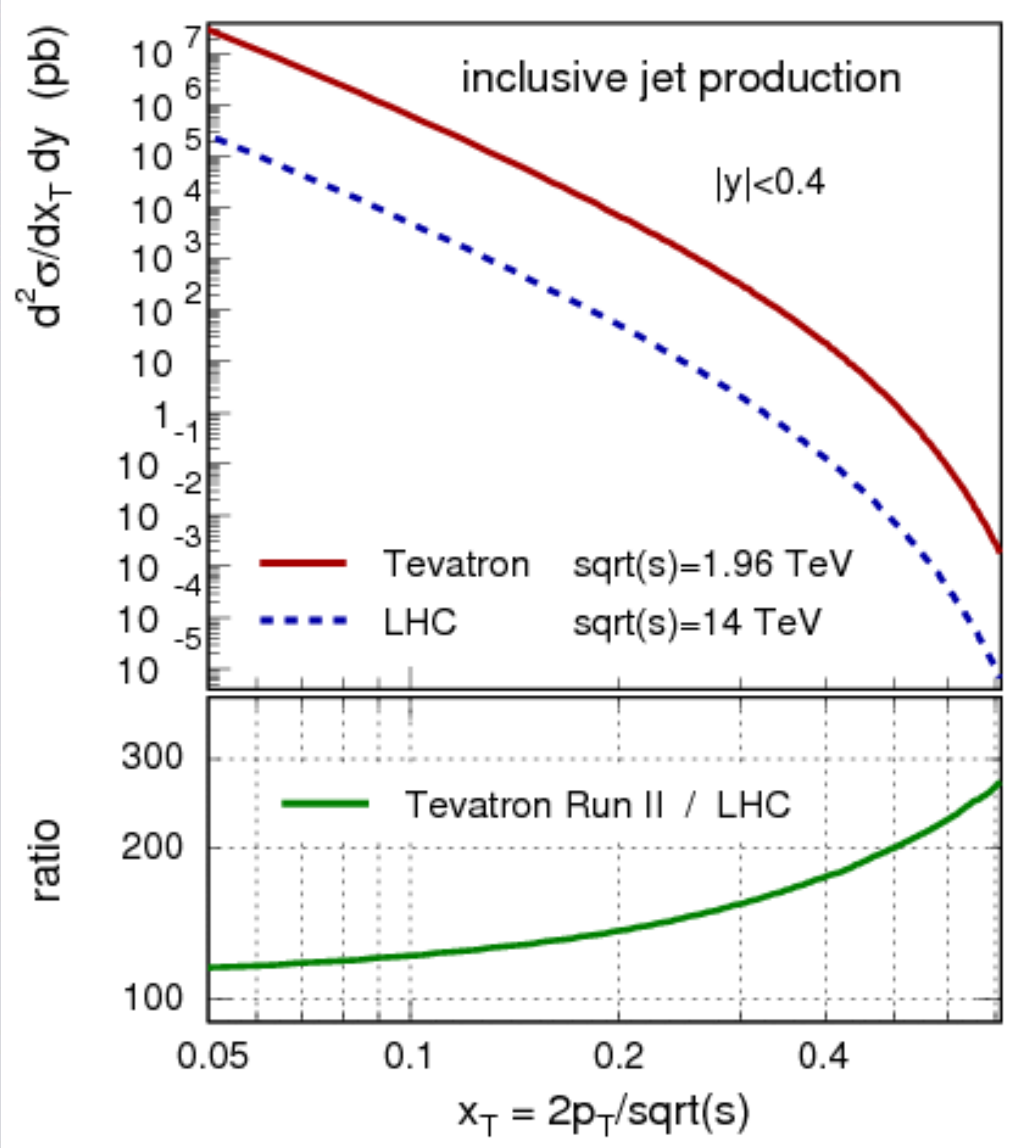


- NLO + 2-loop threshold corrections
- MSTW2008NNLO PDFs
- Extends results from HERA to high p_T

Very precise α_s measurement:

$$\alpha_s(M_Z) = 0.1161^{+0.0041}_{-0.0048}$$

Inclusive Jets: Tevatron vs LHC



PDF sensitivity:

→ compare jet cross section at fixed $x_T = 2\,p_T$ / sqrt(s)

Tevatron (ppbar)

>100x higher cross section @ all x_T

>200x higher cross section @ $x_T > 0.5$

LHC (pp)

- need more than 2400 fb^{-1} luminosity to improve Tevatron@12 fb^{-1}
- more high-x gluon contributions
- but more steeply falling cross sect. at highest p_T (=larger uncertainties)

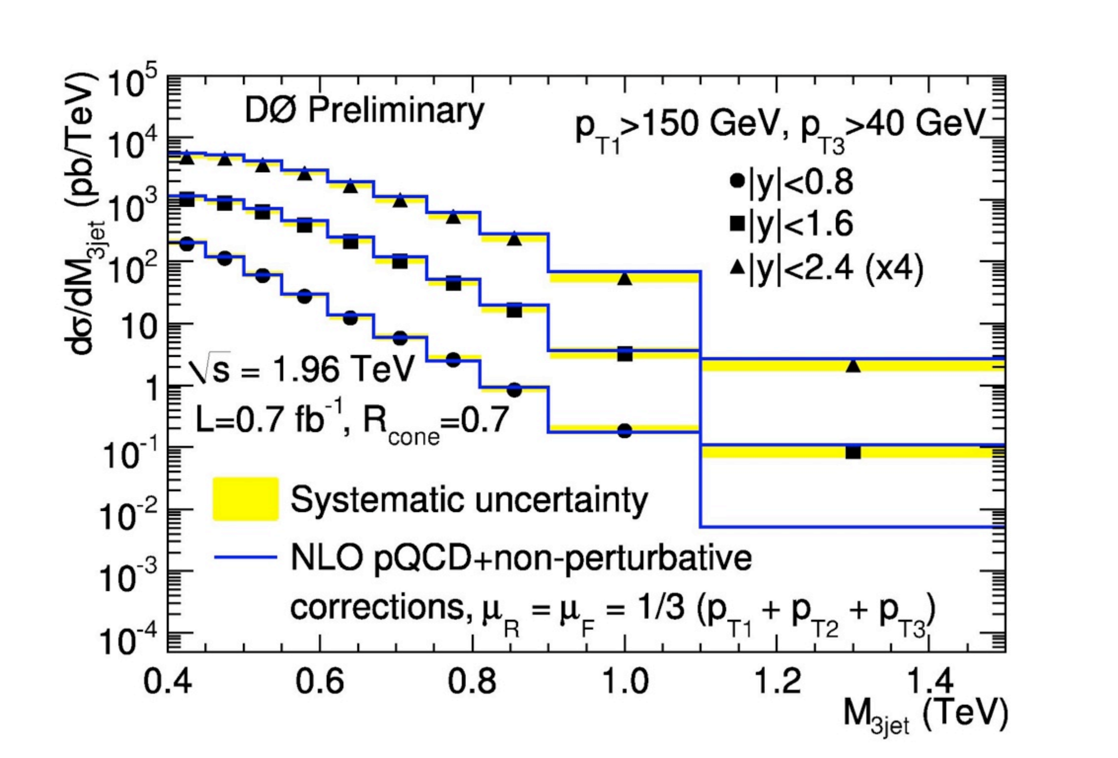
Tevatron Results will dominate high-x gluon for several years

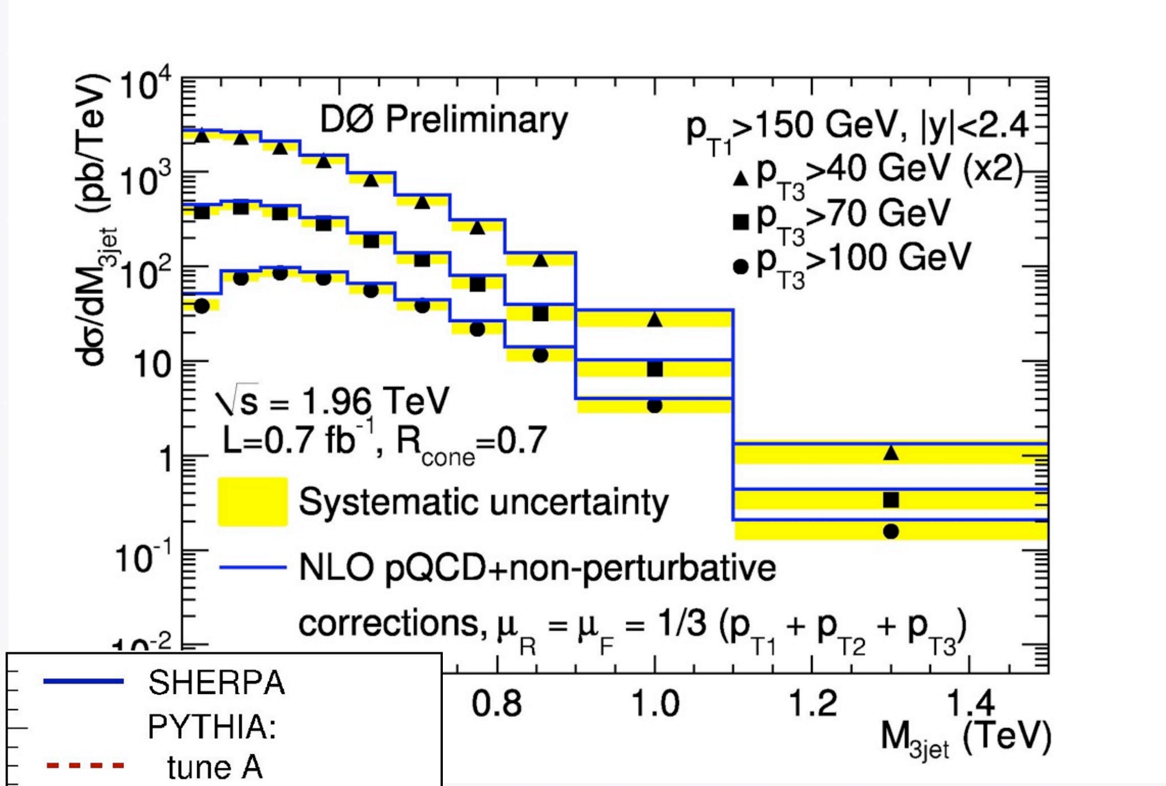
Trijets and R3/2

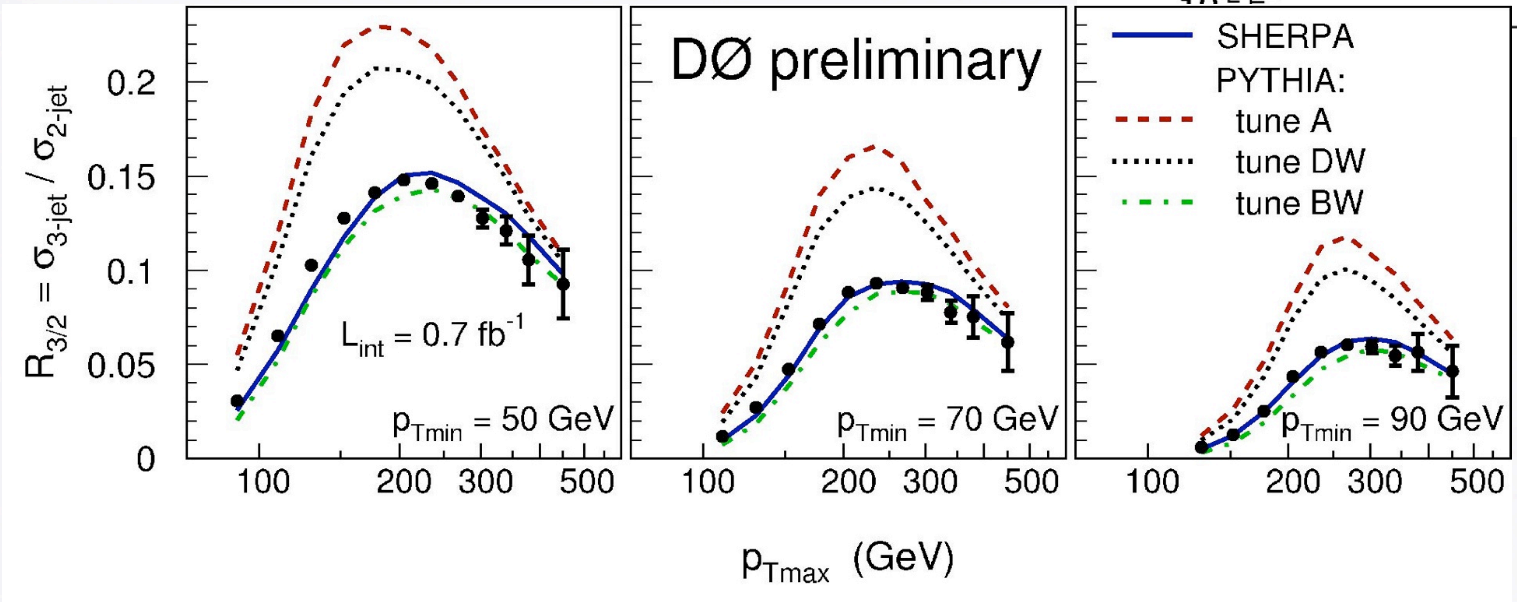
- Tests of pQCD at high jet multiplicity
- Additional opportunities to extract α_s (future)

Differential cross sections measurements:

- data are corrected to particle level
- particle level measurements are compared to NLO theory
- NLO theory is corrected to particle level using parton shower MC



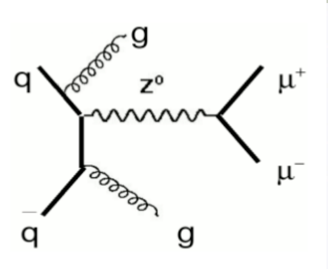




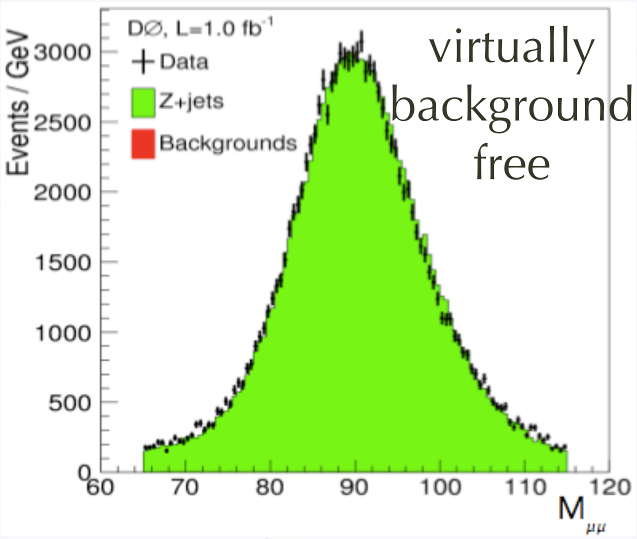
Vector Boson + jets

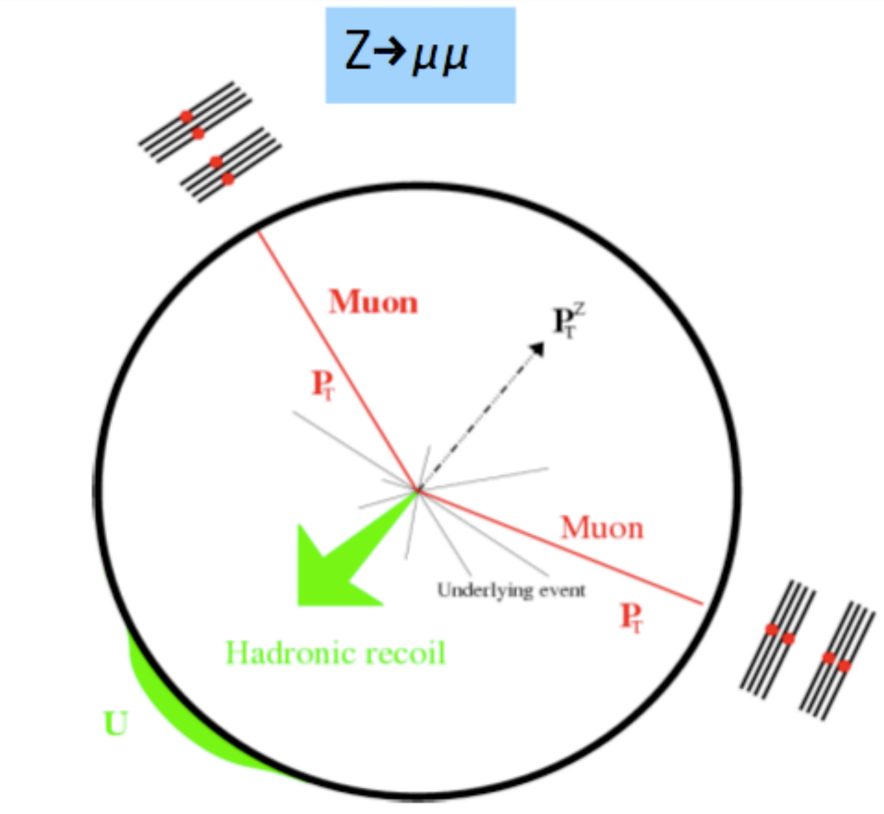
Z + jets

Z->ll + jet + X



- Z provides colorless probe of collision and hard scale; study kinematics of hadronic recoil
- Z boson decay products (leptons) and jets measured, calibrated
- strict muon isolation cuts provide background free data sample
- corrections applied for acceptance, trigger losses
- data unfolded to particle level
  - accounts for detector resolution and efficiency
- comparisons to predictions
  - NLO pQCD via MCFM
    - Pythia hadronization corrections applied
  - LO ME-PS models - ALPGEN, SHERPA
  - LO PS models - PYTHIA, HERWIG





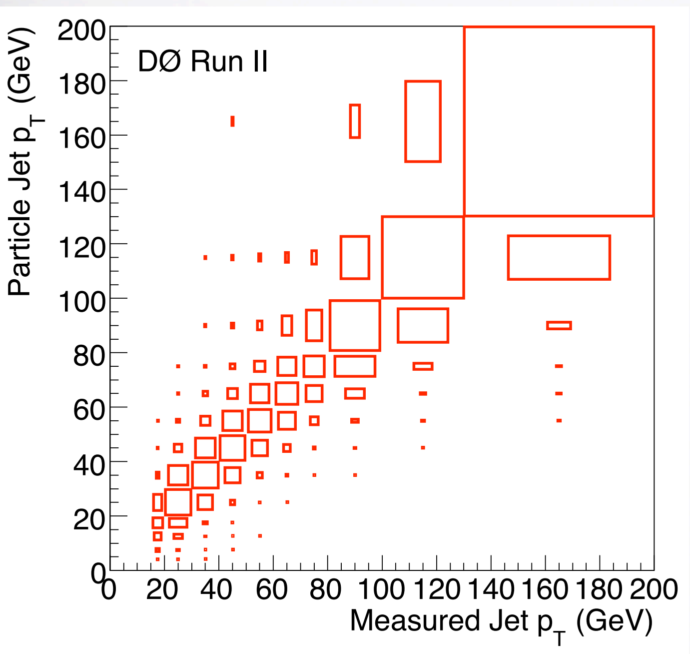
Z+Jets

Z->μμ + jet + X

$\mathcal{L}$ = 1.0/fb

Phase space:
65 GeV< $M_{\mu\mu}$ < 115 GeV,
R_{cone}=0.5, **p_T^{jet} > 20 GeV**
$|y^{jet}| < 2.8$, $|y^{\mu}| < 1.7$

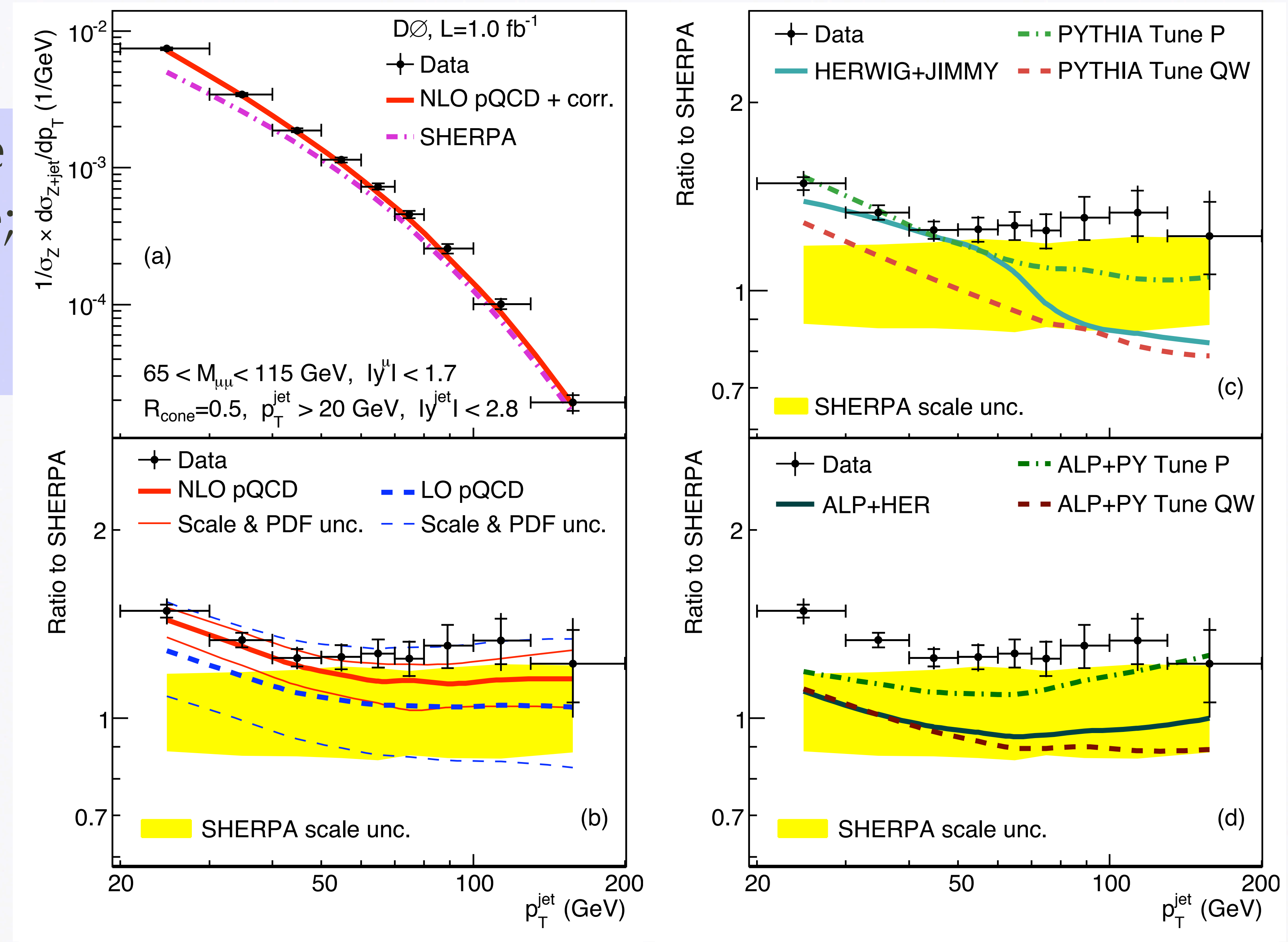
Z provides colorless probe of collision and hard scale; study kinematics of hadronic recoil



migration matrix
-> used to unfold data
large migrations, especially at low p_T

Cross section as a function of p_T^{jet}

ratios relative to Sherpa v1.1.3



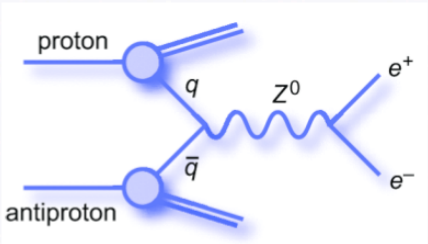
Data described by NLO theory

Large variations between Pythia tunes

Phys. Lett. B 669, 278 (2008)

Z+Jets

Z->ee + **2jets** + X

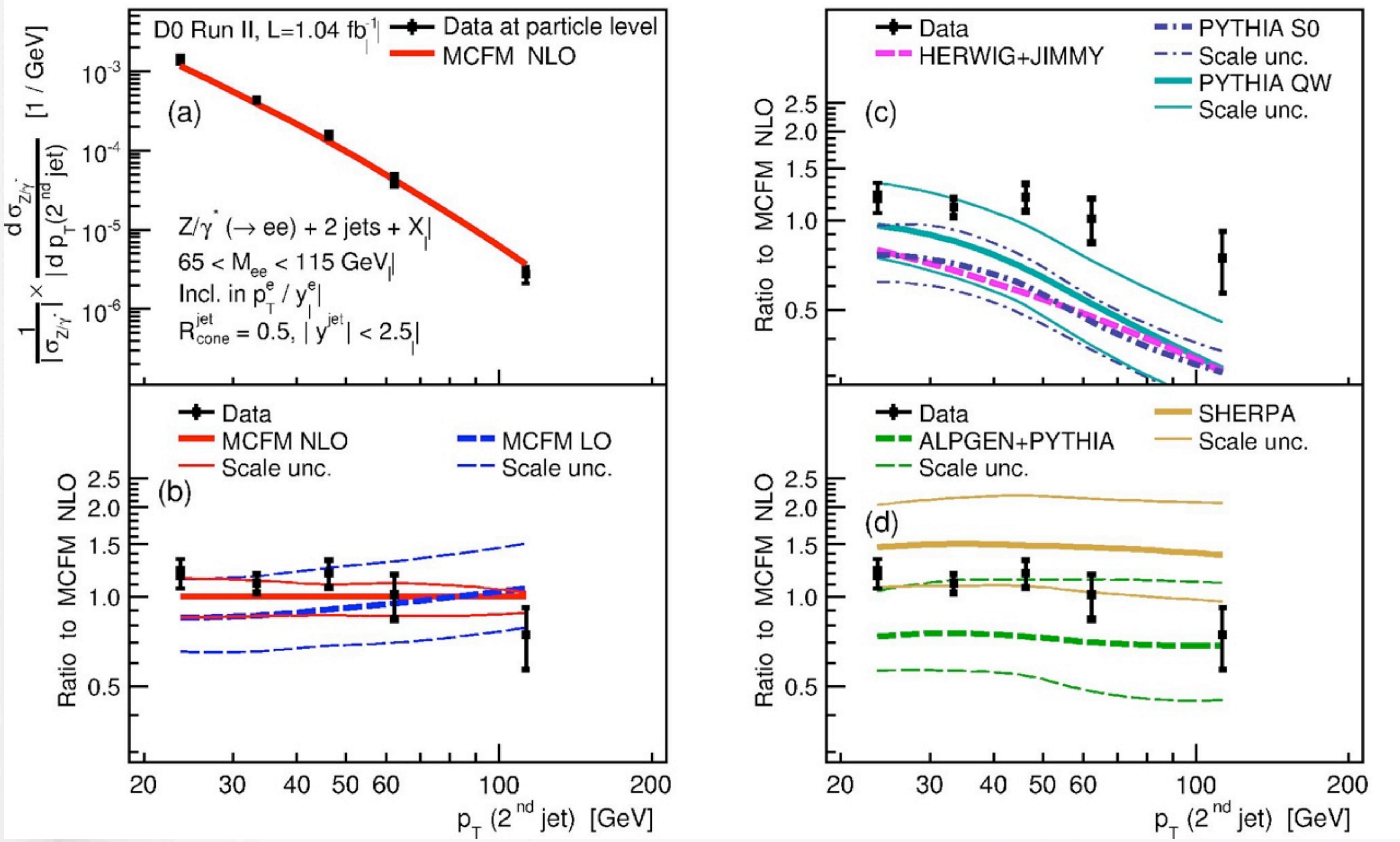


Particle level phase space:
65 GeV< M_{ee} < 115 GeV,
D0 midpoint R_{cone}=0.5, p_T^{jet} > 20 GeV
$|y^{jet}|$ < 2.5, Incl in $p_T^e/|y^e|$

Direct measurement of jet kinematics with large multiplicities

ratios relative to MCFM NLO

MCFM v5.3 PDF: CTEQ6.6M
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$



PYTHIA v6.416
Pythia Tune SO
Pythia Tune QW
HERWIG v6.510
+JIMMY v4.31

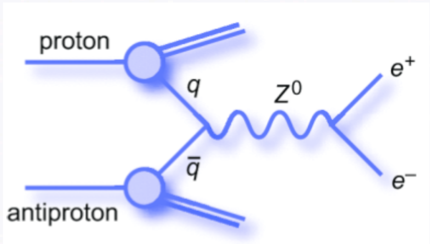
ALPGEN v2.13
+PYTHIA v6.325
SHERPA v1.1.1

- ✦ Large differences between models
- ✦ Small experimental errors, dominated by statistics

PLB 678, 45 (2009)

Z+Jets

Z->ee + **3jets** + X

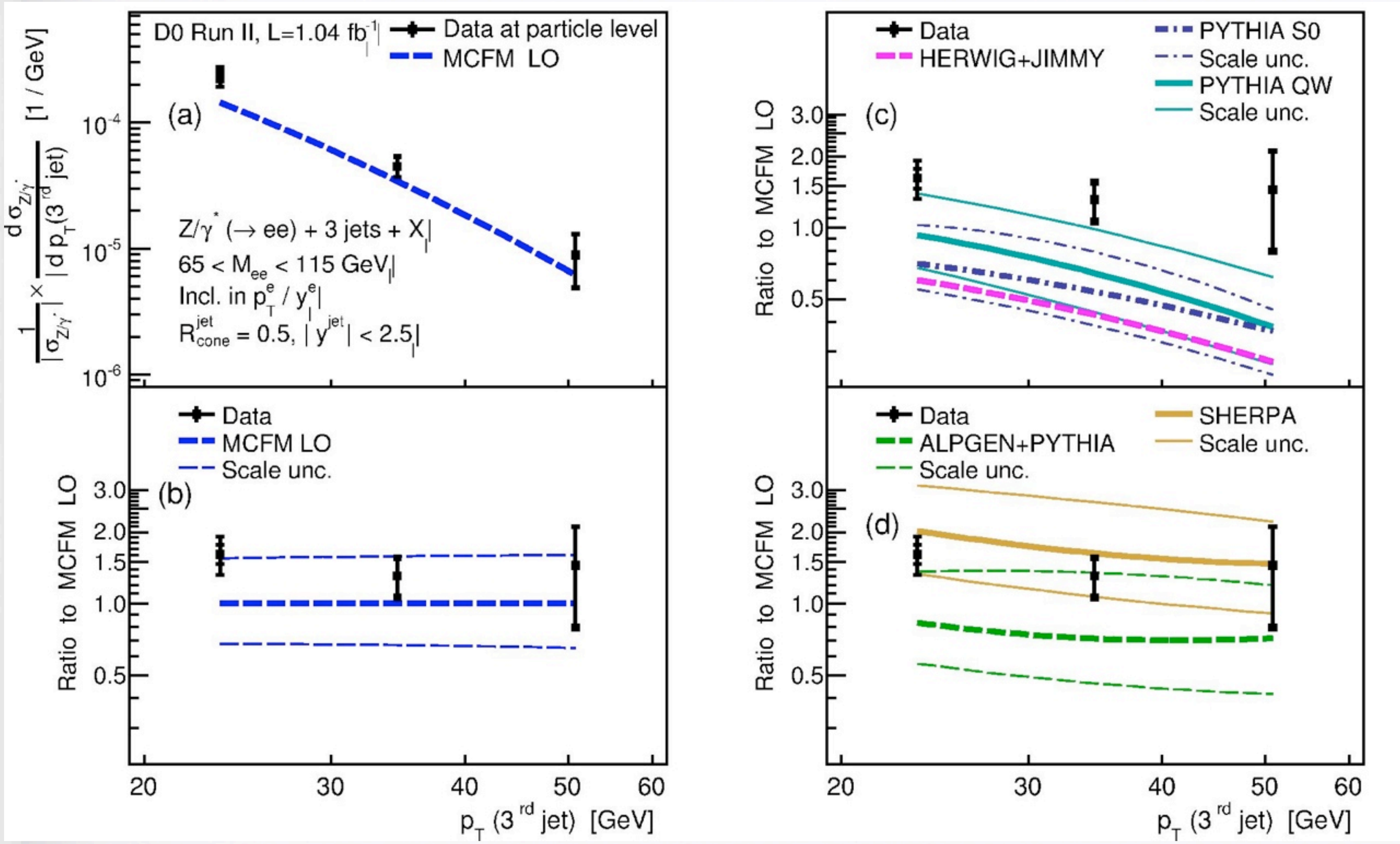


Particle level phase space:
65 GeV< M_{ee} < 115 GeV,
D0 midpoint R_{cone}=0.5, p_T^{jet} > 20 GeV
$|y^{jet}|$ < 2.5, Incl in $p_T^e/|y^e|$

Direct measurement of jet kinematics with large multiplicities

ratios relative to MCFM LO

MCFM v5.3 PDF: CTEQ6.6M
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$



PYTHIA v6.416
Pythia Tune SO
Pythia Tune QW
HERWIG v6.510
+JIMMY v4.31

ALPGEN v2.13
+PYTHIA v6.325
SHERPA v1.1.1

- ✦ Large differences between models
- ✦ Small experimental errors, dominated by statistics

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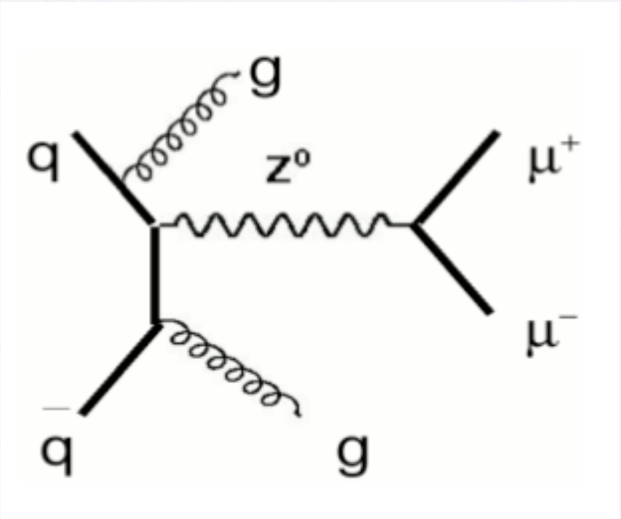
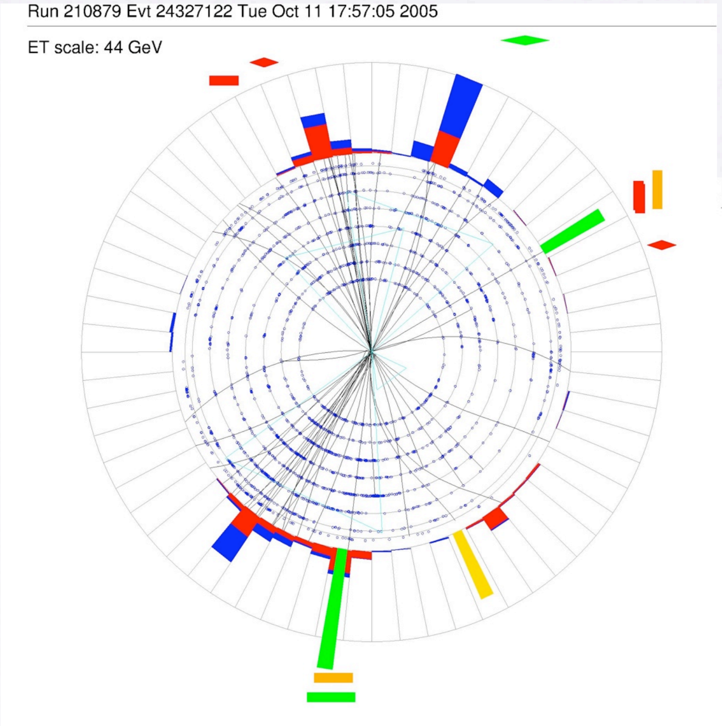
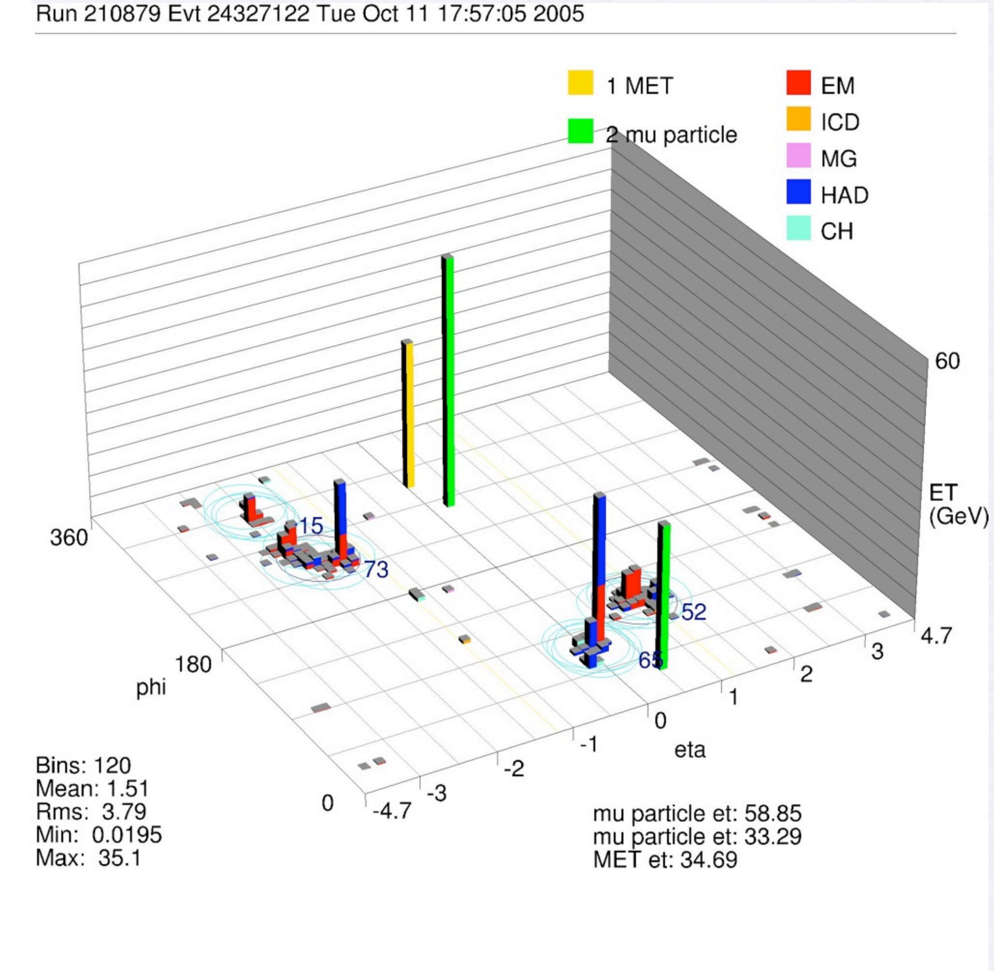
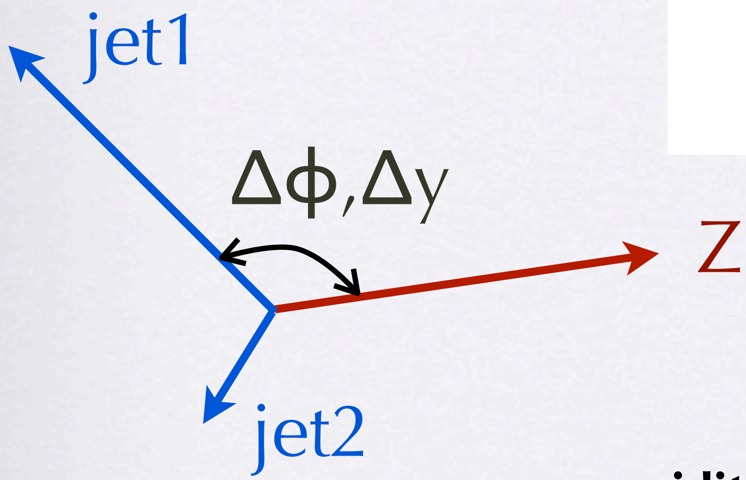
Z+jets - angular observables

- further constrains kinematics
- test of PS model assumptions
- first measurements at hadronic collider of
  - $\Delta\phi$(Z,leading jet)
  - Δy(Z,leading jet)
  - $y_{boost} = 1/2(y_Z + y_{jet})$









rapidity $y = 1/2 \ln(E+p_z/E-pz)$

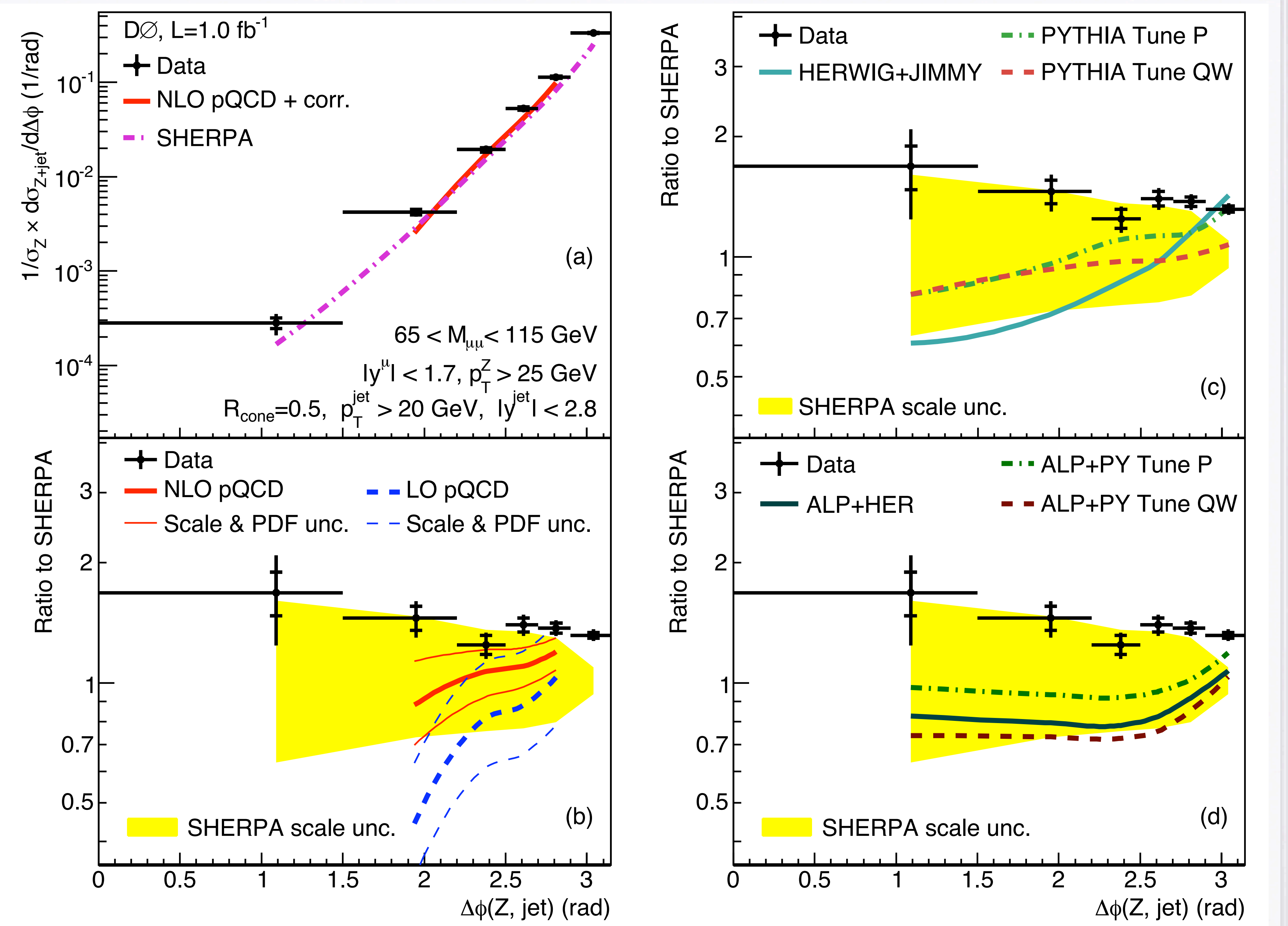
$\eta = -\ln(\tan\theta/2)$

Z+jets

$\Delta\phi$ (Z,jet)
Δy (Z,jet)
$y_{boost}(Z,jet) = ½(y_Z+y_{jet})$

Angular distributions sensitive to additional QCD radiation

Phase space:
65 GeV< $M_{\mu\mu}$ < 115 GeV,
R_{cone}=0.5, p_T^{jet} > 20 GeV
$|y^{jet}|$ < 2.8, $|y^{\mu}|$ < 1.7
p_T^Z > 25 GeV
(avoid soft effects)

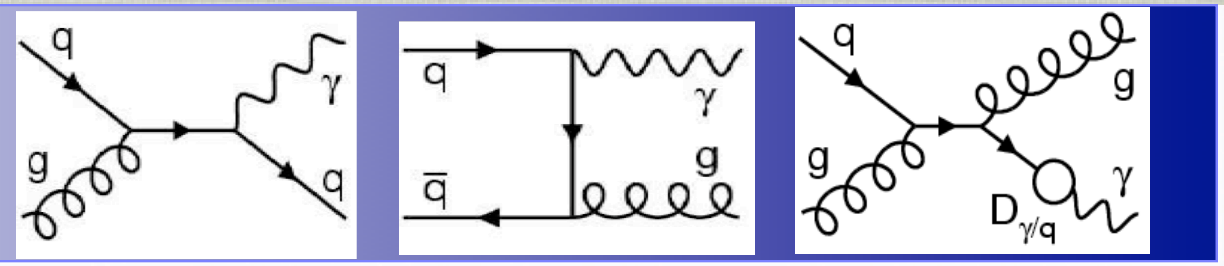


Small values of $\Delta\phi$(Z,jet) excluded from MCFM due to importance of non-perturbative effects

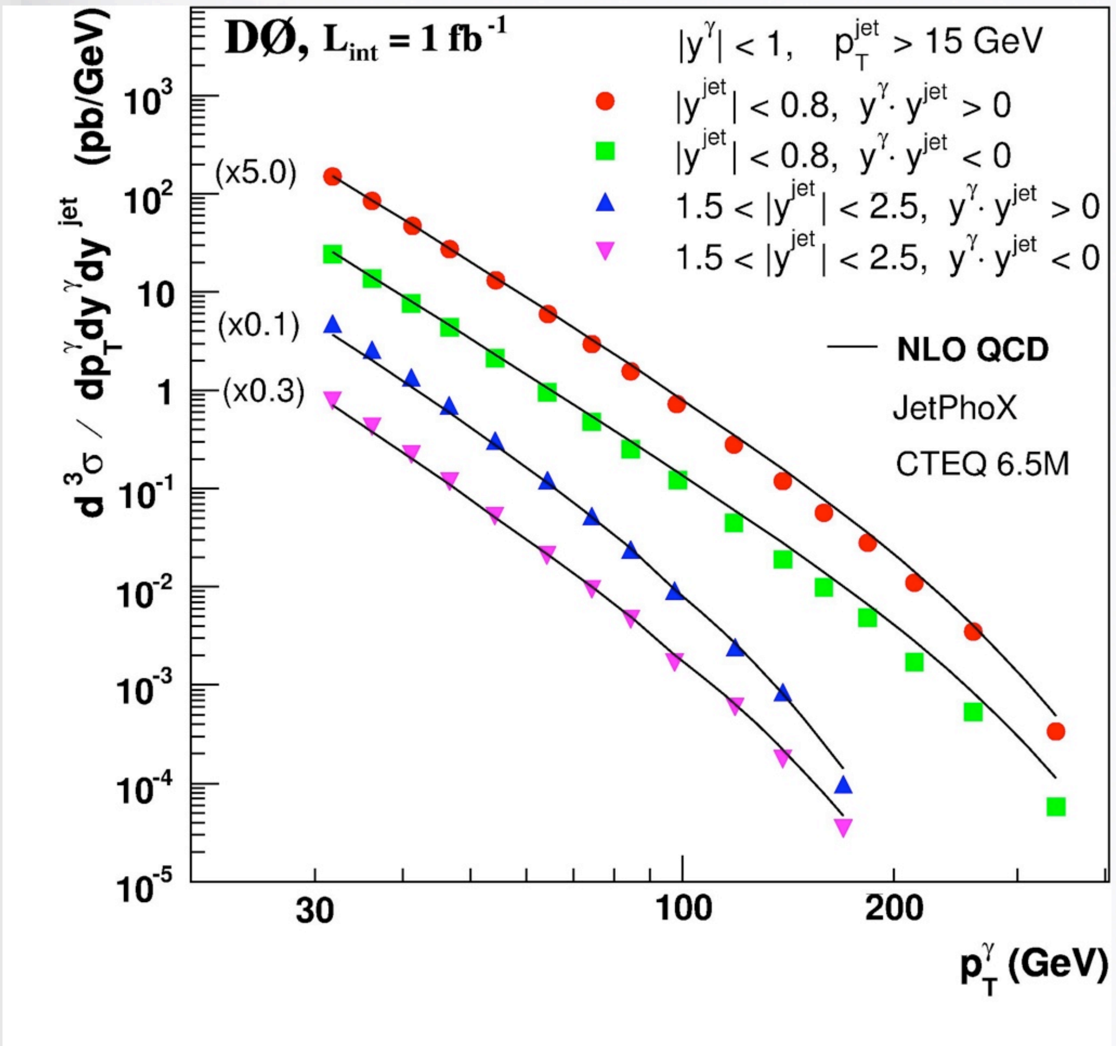
Sherpa describes shape of all distributions

Phys. Lett. B **682**, 370 (2010), arXiv.org:0907.4286

γ+jets

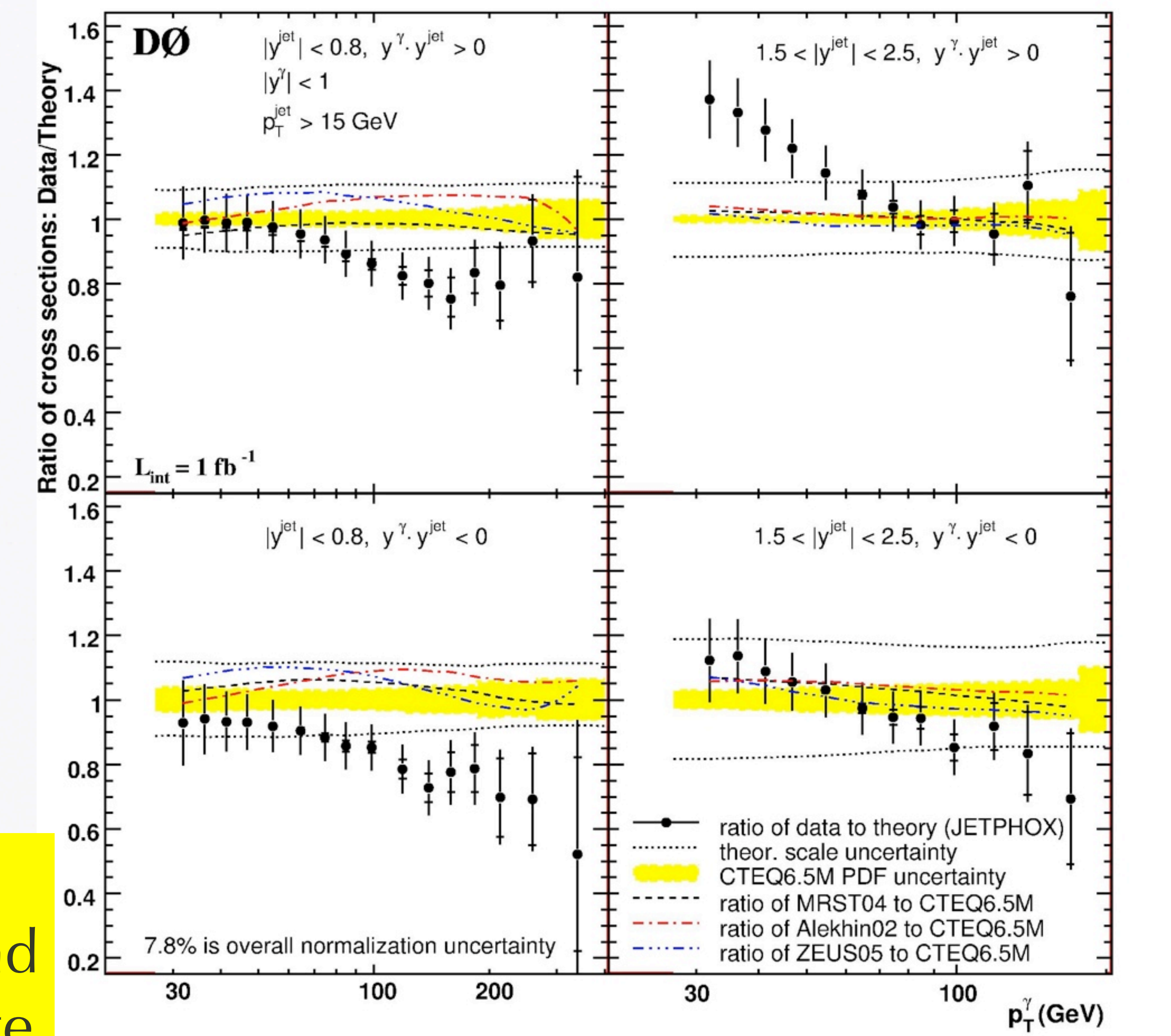


$\mathcal{L}$ = 1.0/fb



Huge statistics compared to W,Z
Triple differential cross sections!

Phys. Lett. B 666, 435 (2008), arXiv.org:0804.1107



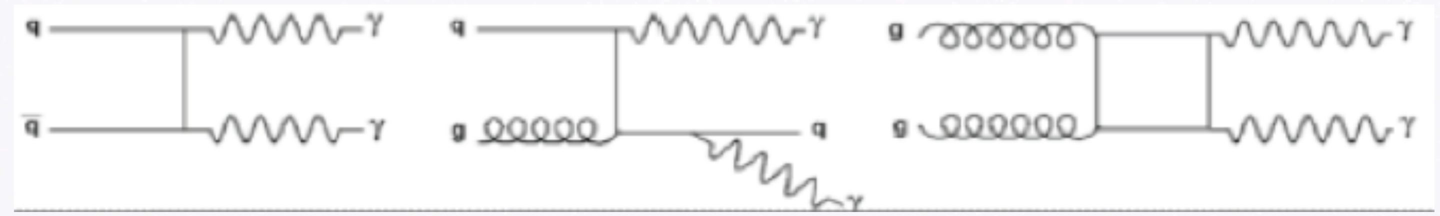
Allows for careful study of dynamics of QCD in different regions of x and Q^2

NLO theory cannot simultaneously describe photon p_T and jet rapidity over entire measured range

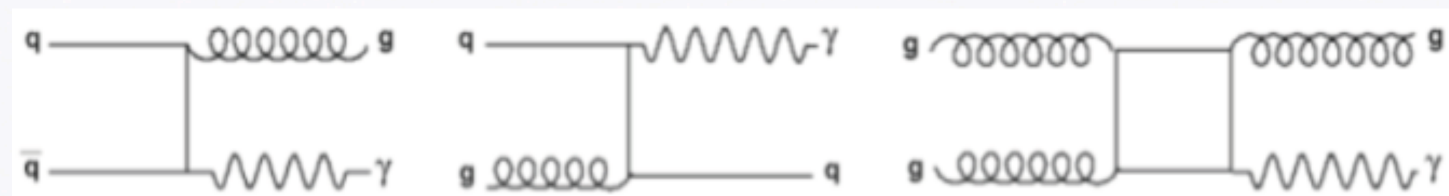
Phys. Lett. B **666**, 2435 (2008), arXiv.org:0804.1107

Prompt Diphoton Production

- Prompt diphotons are produced directly in hard scattering or through quark fragmentation

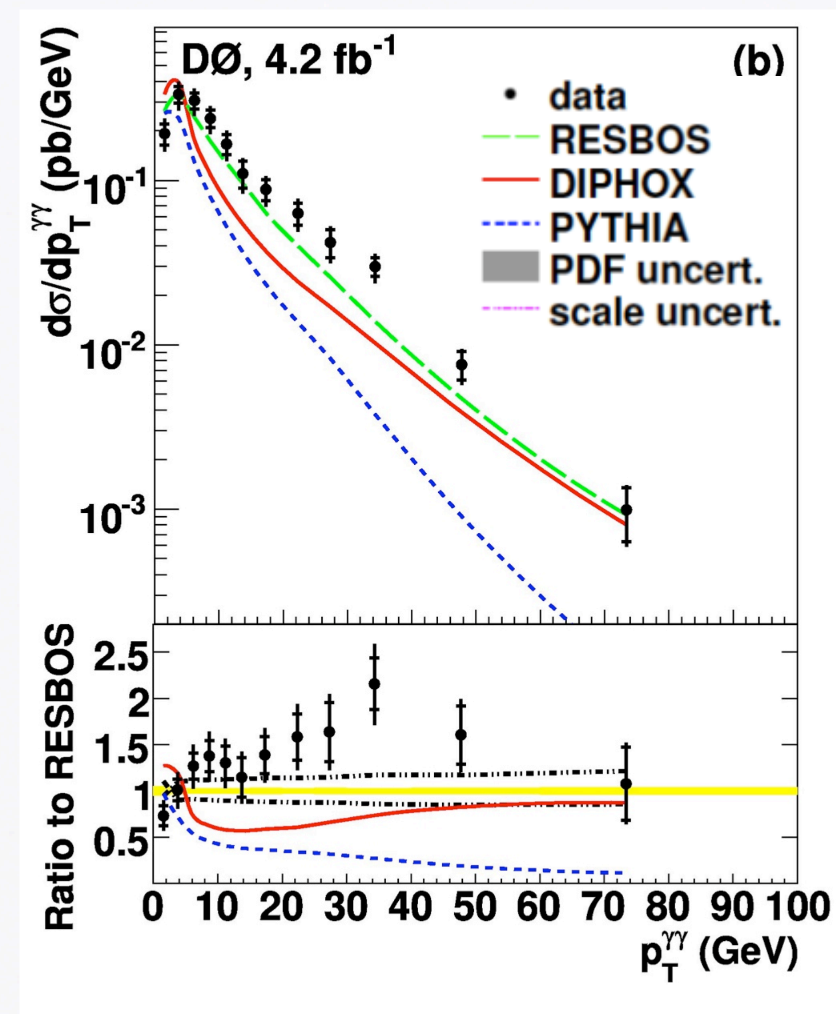


- Main backgrounds are photon+jet or dijet events



H->γγ currently main channel for SM Higgs discovery at low mass at LHC

Data have harder spectrum than predictions



Theory predictions:
PYTHIA: Parton Shower
DIPHOX: fixed order NLO calculation
RESBOS: Resummed calculation (to NNLL)

Phys. Lett. B **690**, 108 (2010), arXiv.org:1002.4917

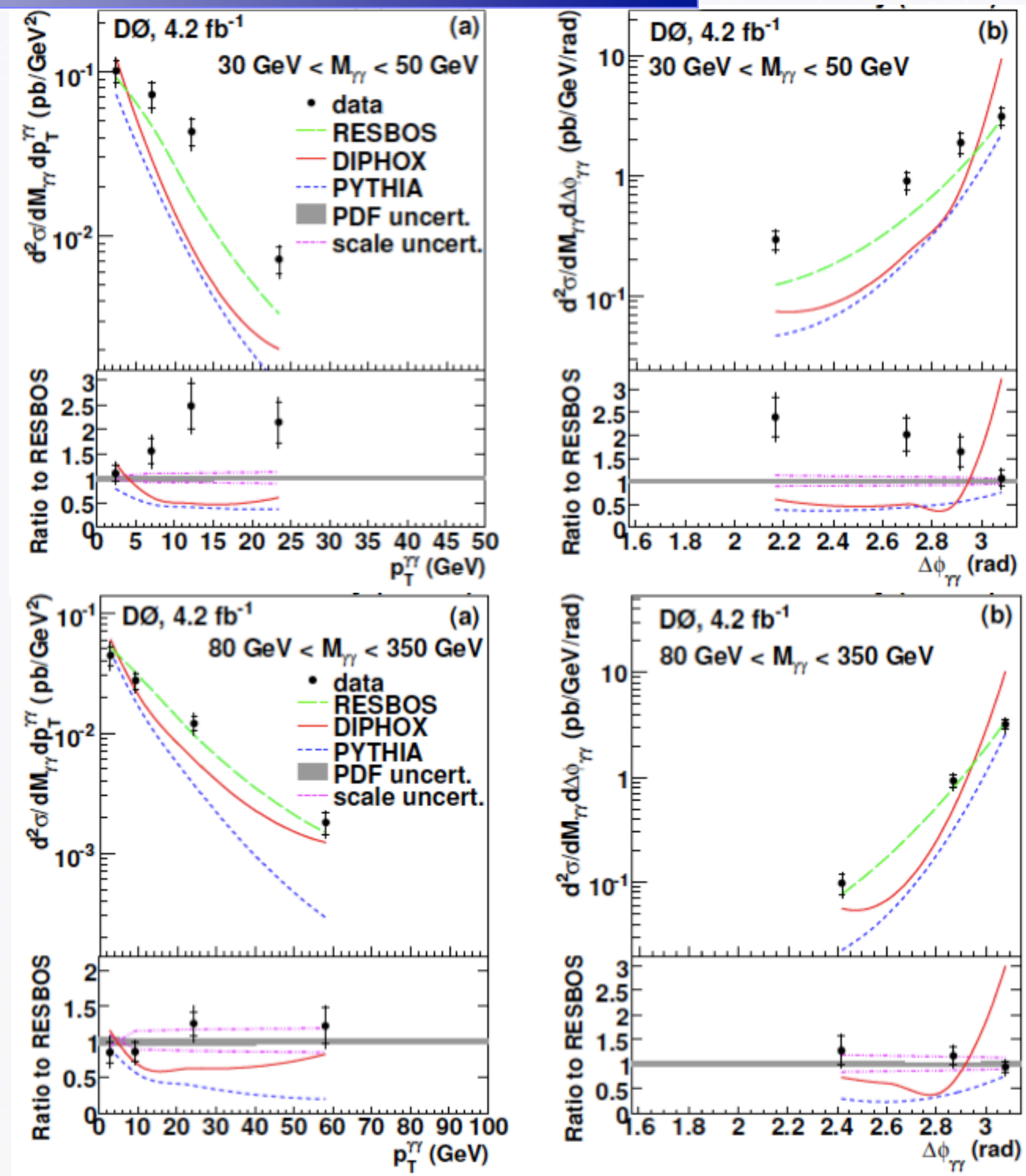
Prompt Diphoton Production

30 GeV < $M_{\gamma\gamma}$ < 50 GeV

Further inspection of double differential cross sections separates low and high mass kinematics

80 GeV < $M_{\gamma\gamma}$ < 350 GeV

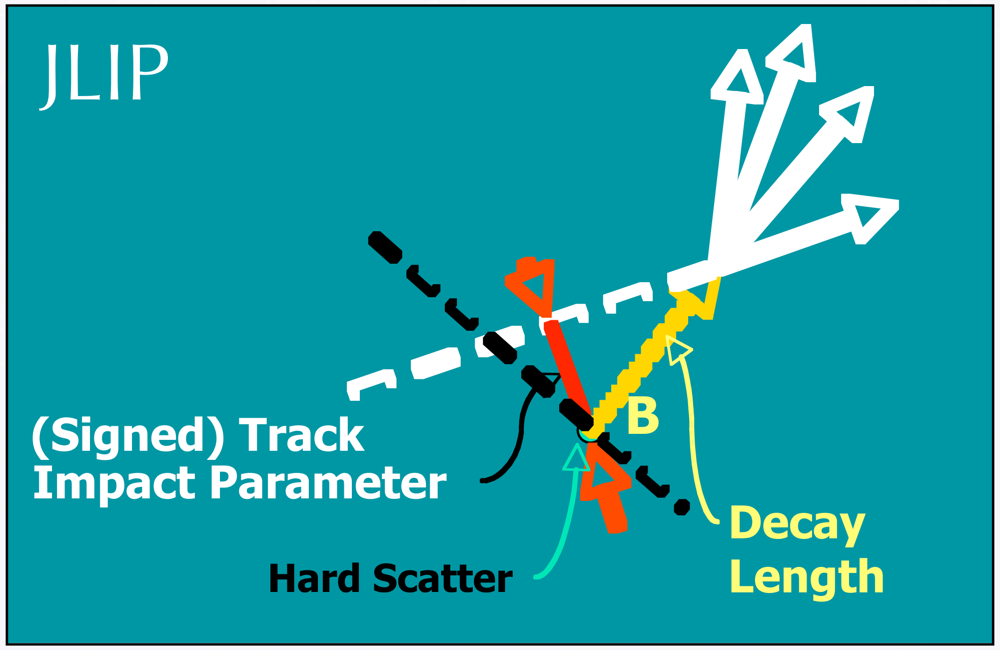
In region where SM Higgs and New Physics is of most interest, RESBOS gives excellent data description



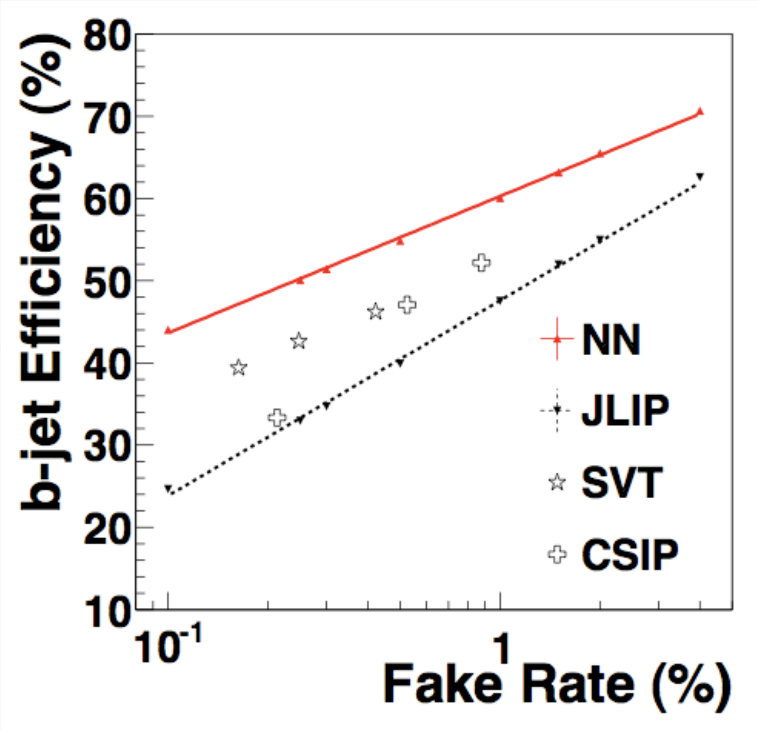
Z/γ* + heavy flavor jets

Heavy flavor tagging

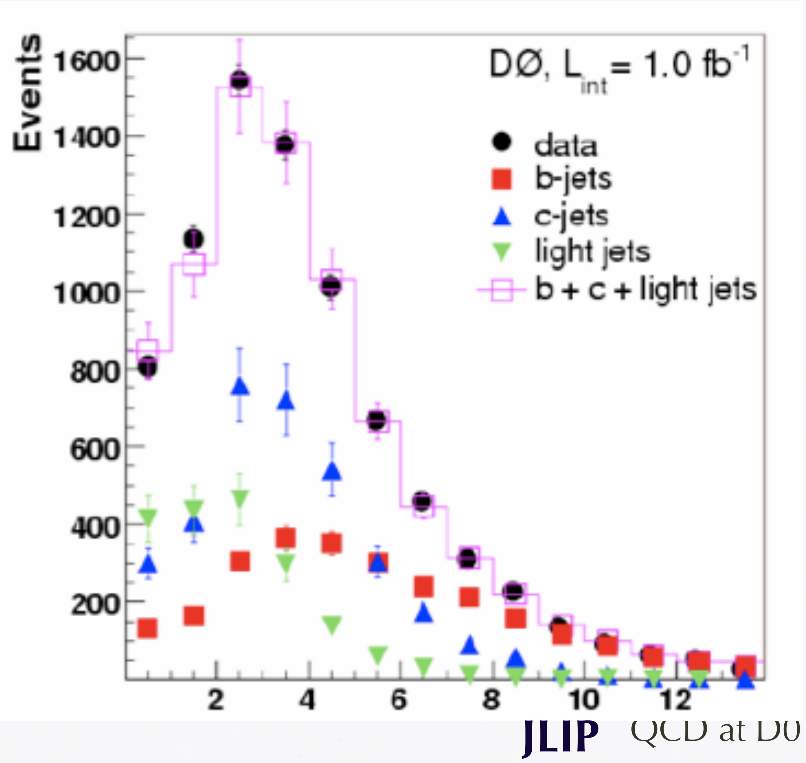
<u>Several approaches</u>
Secondary Vertex Finding
Impact Parameter
Neural Network
} or combinations



- QCD analyses rely mainly on Jet Lifetime Probability discriminant (JLIP)
  - ➡ confidence level that all tracks in a jet originate from the primary interaction

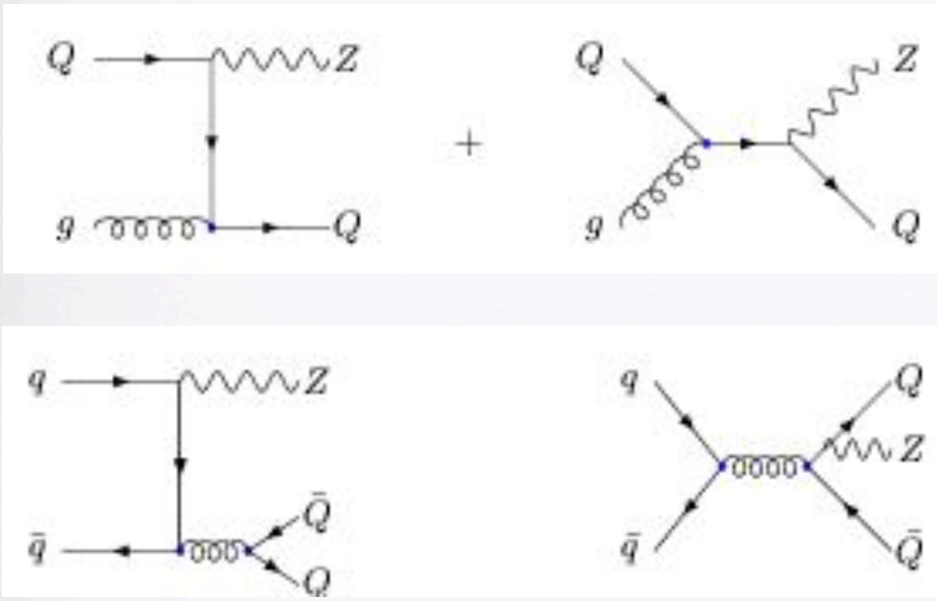


- Flavor fractions are determined for b, c and light jets by fitting with data or MC templates



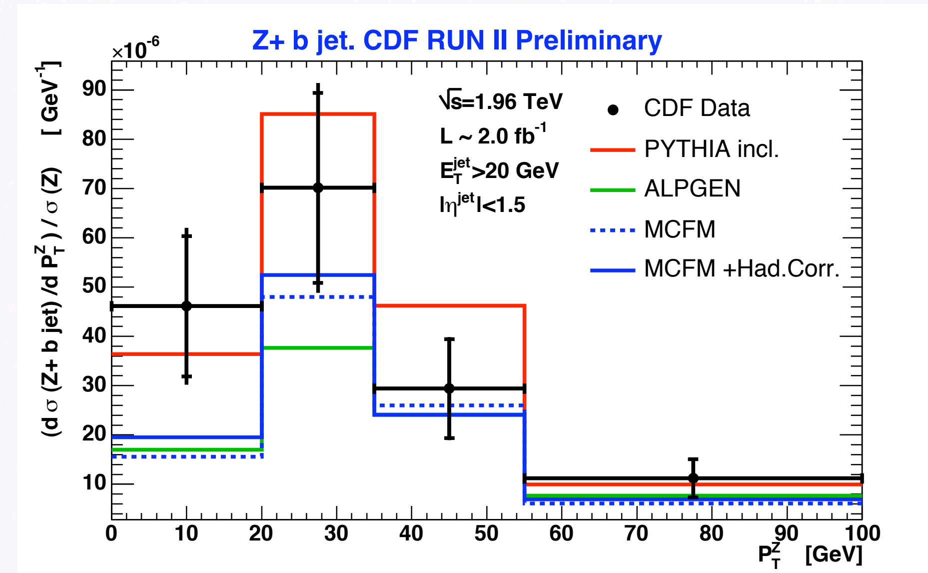
Future plan: move to NN tagging

Z+b jets

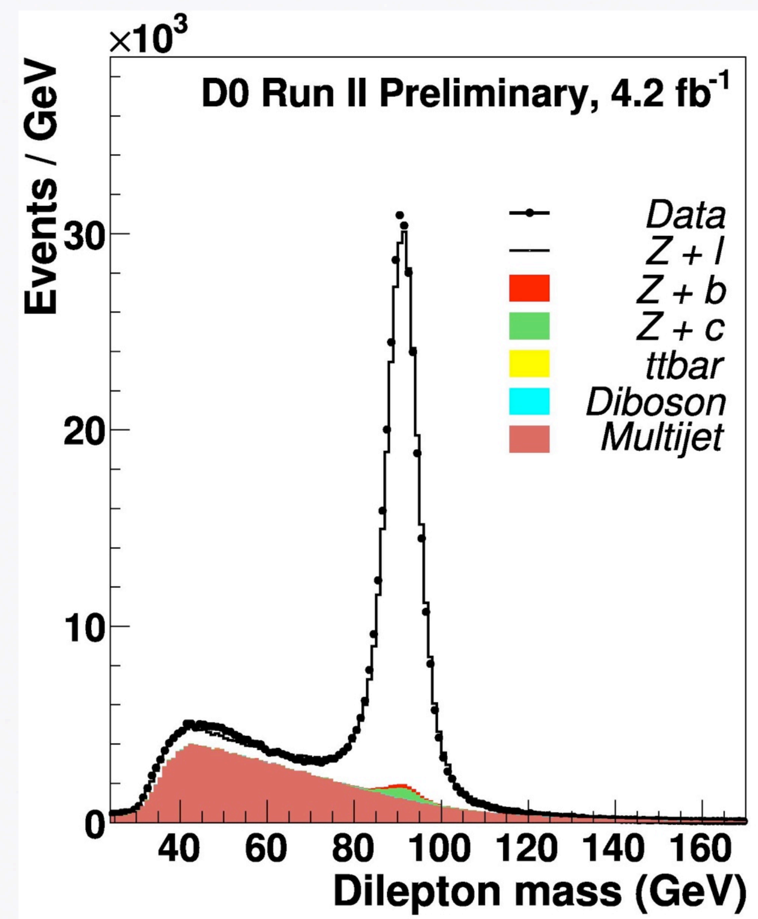


CDF: 2σ discrepancy with NLO pQCD in first bin

Statistics limited measurement

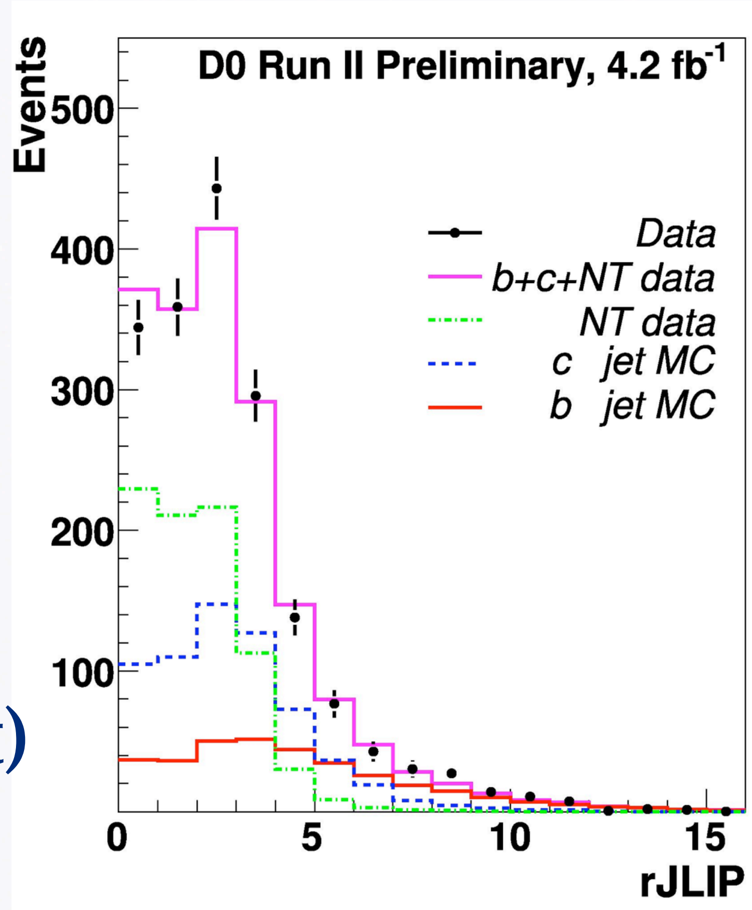


- ❖ Interesting test of pQCD predictions and b-quark fragmentation.
- ❖ Important background to the SM Higgs search in the ZH(→bb) channel.
- ❖ Probe of b-quark parton distribution function
- ❖ σ(Z+b) / σ(Z+j) benefits from cancellations of many systematic uncertainties
  ⇒ precise comparison with theory



Z+b jets

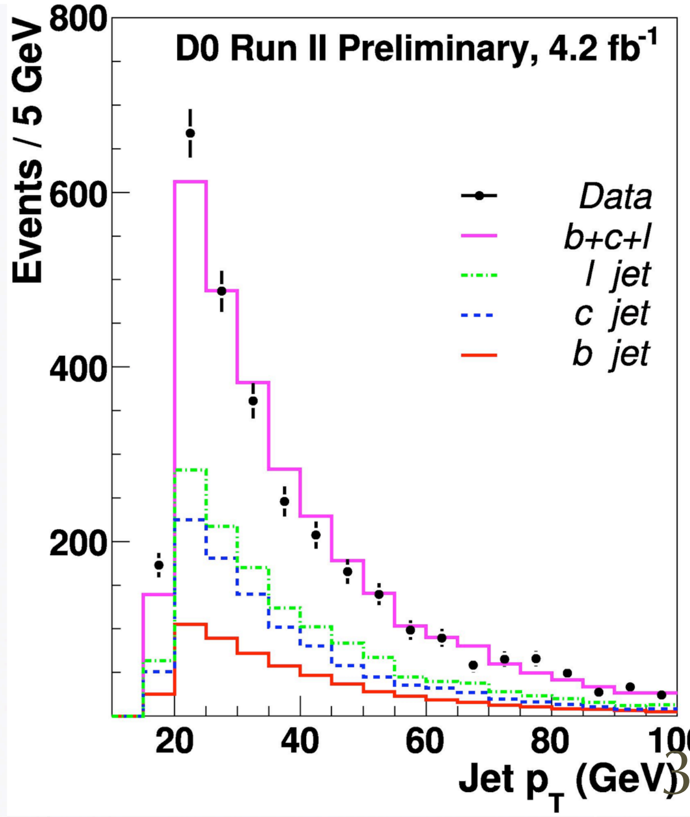
- Jet flavor fractions determined from maximum likelihood fits of Monte Carlo b, c templates and negative-tag (NT) data for light contribution
- Using extracted fractions, jet p_T distribution is well-described



Z+b/Z+jet = .0176 ± .0024(stat) ± .0023 (syst)
-- in agreement with NLO pQCD
(which has 20-25% scale uncertainty)

CDF result: .0208 ± .0033(stat) ± .0034 (syst)
-- also agrees with NLO theory

D0 γ+b differential cross section vs p_T also in agreement with NLO (future slide)



- What about W+b?

W+b jets

CDF has big discrepancy with NLO in this measurement

→ D0 has embarked upon a measurement

Wbb is dominant background in low-mass Higgs search

b-fraction determined from likelihood fit to M_{vert}

Measure: σ(W+b jets)x BR(W->lν)

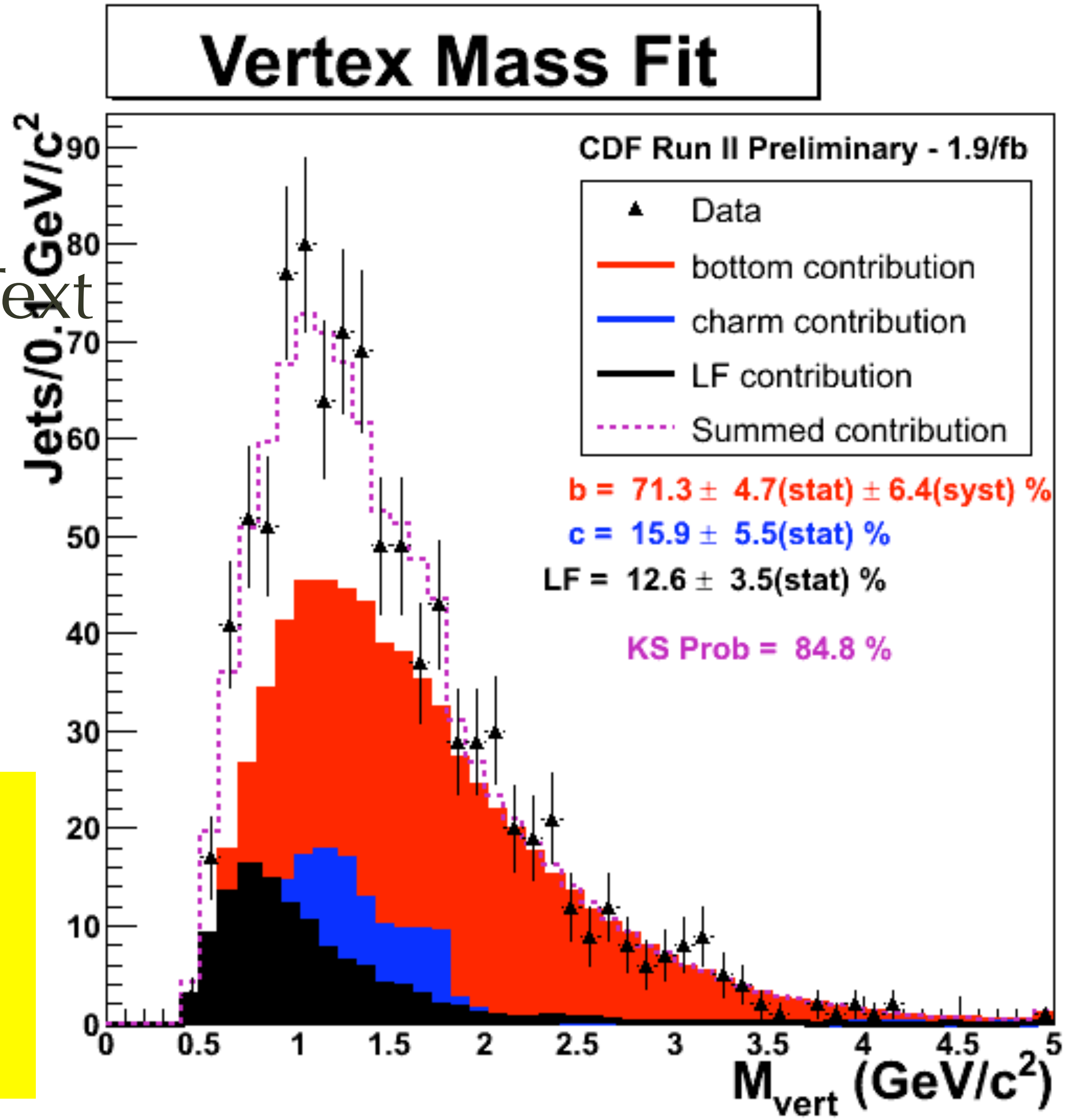
Alpgen prediction: 0.78 pb
Pythia prediction: 1.10 pb
NLO prediction: 1.22 ± 0.14 pb

Result:
2.74 ± 0.27 (stat) ± 0.42 (sys) pb
→ 2.5-3.5x bigger!

Discrepancy with NLO and LO MC - suggestive of need for improved theory:

- higher order corrections
- b-quark fragmentation model

Text



Submitted to PRL

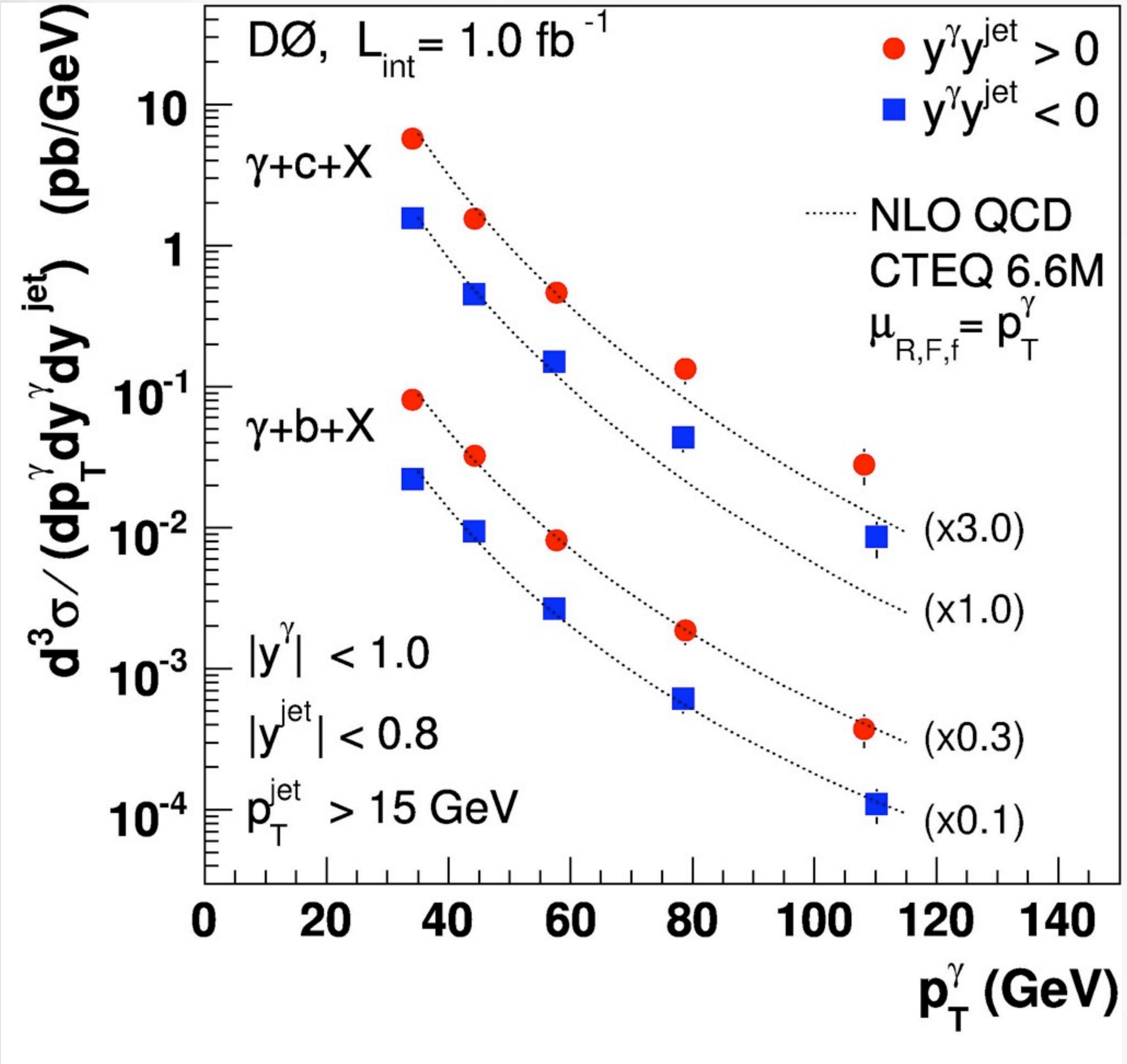
γ+b,c jets

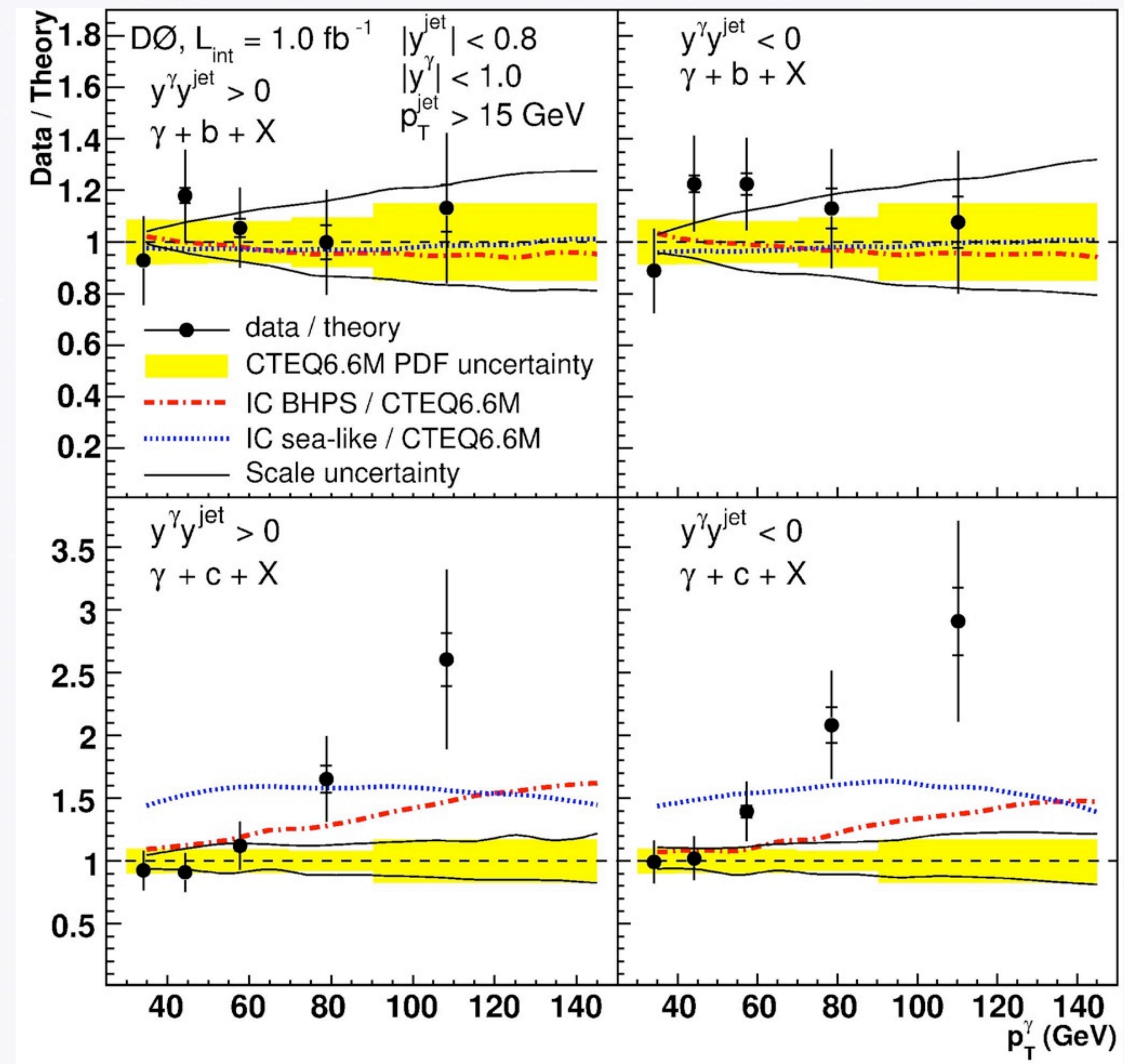
$\mathcal{L}$ = 1.0/fb

Sensitive to heavy-quark PDF
at higher x and Q^2 than HERA

Triple differential cross sections!

Phys. Rev. Lett. **102**, 192002 (2009), arXiv.org:0901.0739

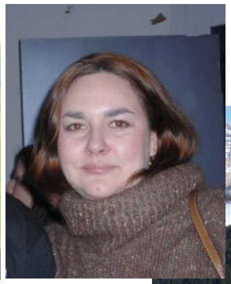
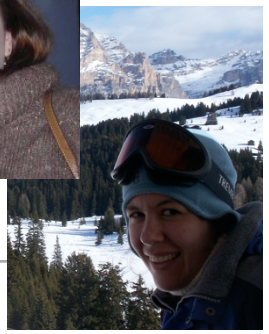




Relevant for heavy quark, gluon PDFs for 0.01< x <0.3

Some disagreement with theory for photon p_T > 70 GeV in γ+c

CDF/D0/Theory V+Jets Working Group

convenors: Sasha Pronko (CDF)
LIdija Zivkovic (D0)
Sabine Lammers (D0)

Charge:

- Facilitate communication between CDF and D0 to coordinate our V+jets measurements in such a way that a coherent physics message is brought to the HEP community
- Facilitate communication between experimentalists and theorists to ensure that
  - good choices of MC parameters are made when comparing data and theory
  - experimentalists are running the theory programs correctly
  - theorists understand the meaning of data measurements
- Provide a forum where algorithmic techniques relevant to V+jets measurements can be discussed, and bring insights back to experiments
- Impress upon the HEP community the importance of understanding these processes as backgrounds to Higgs and BSM searches
- Participate in data storage algorithms: HEPDATA, Rivet, etc.

Soft, diffractive and MPI physics

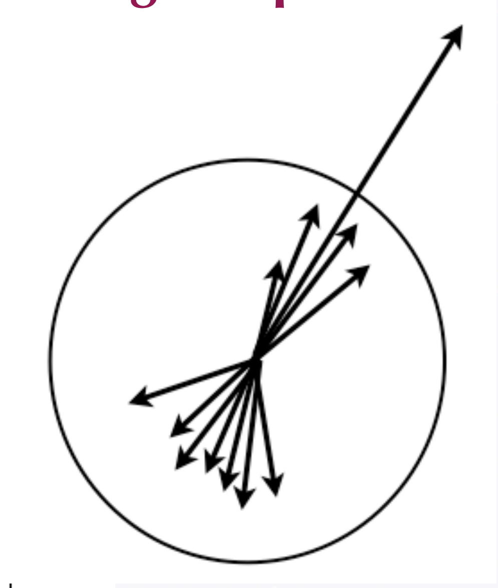
Delta-phi in MinBias Events

MinBias Interactions, Underlying Event

dimuon selection

only study high quality tracks

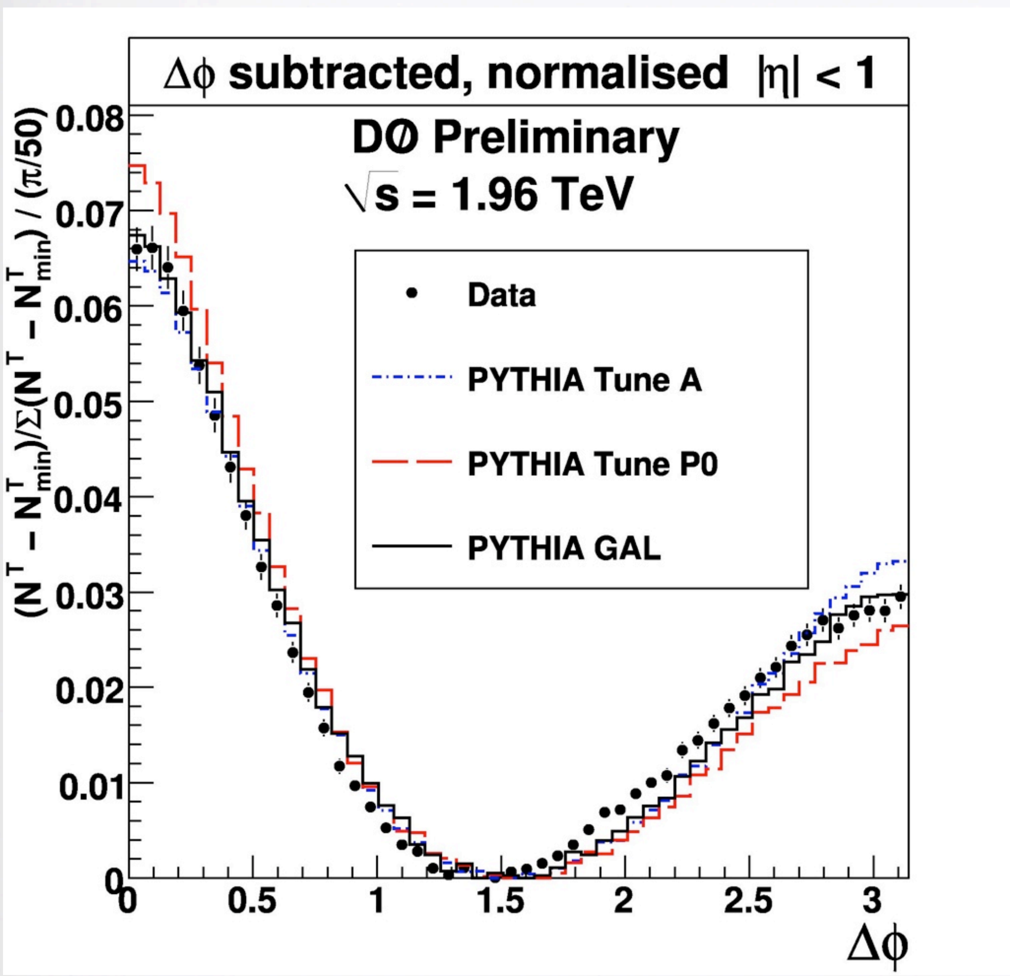
highest p_T track

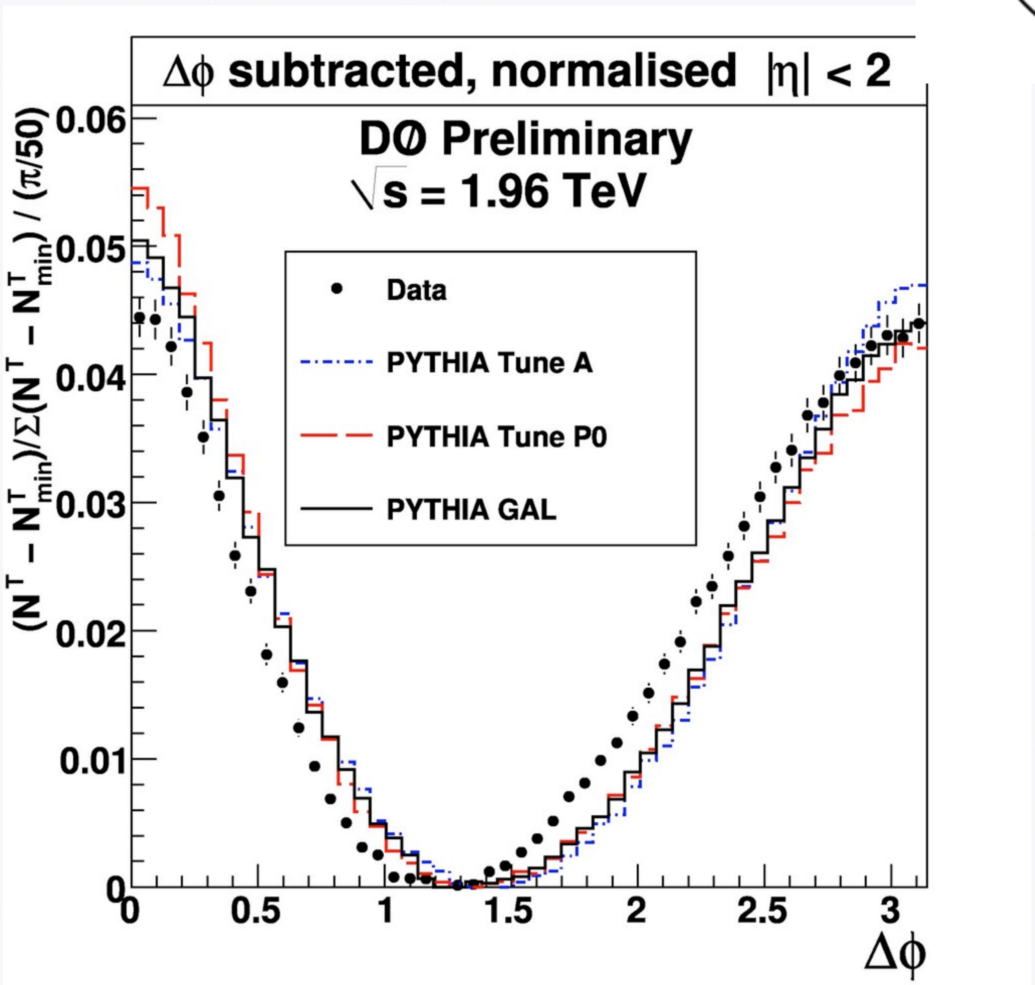


Want simple, inventive variables:

- $\Delta\phi$(highest p_T track, other tracks)
  - robust variable: no correlation for fakes

normalized distributions in two rapidity regions





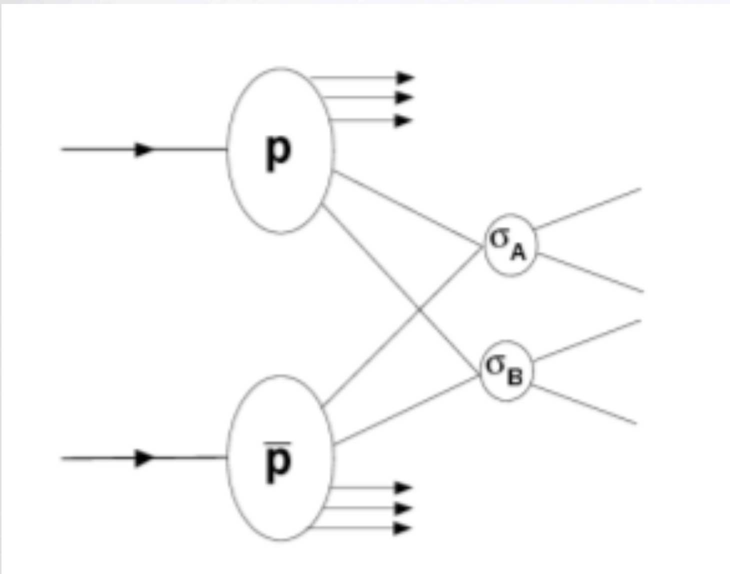
also studying resonance production underneath Z events

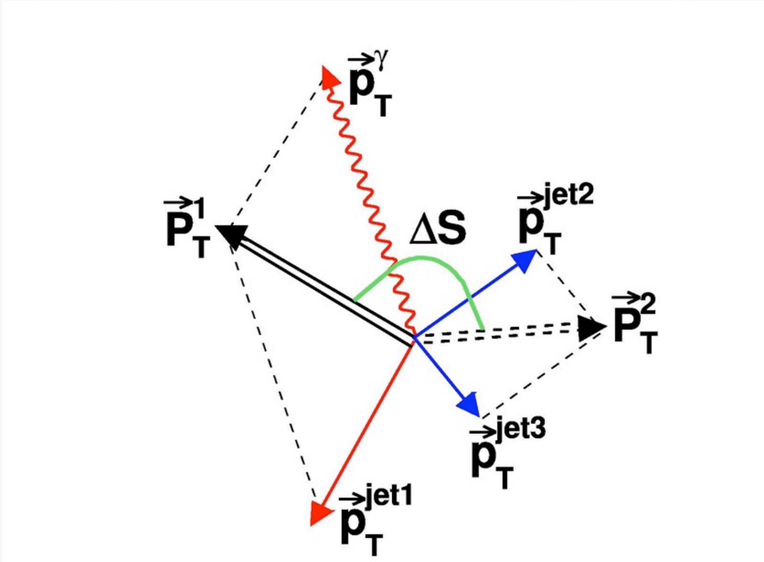
Preliminary Result at DIS2010

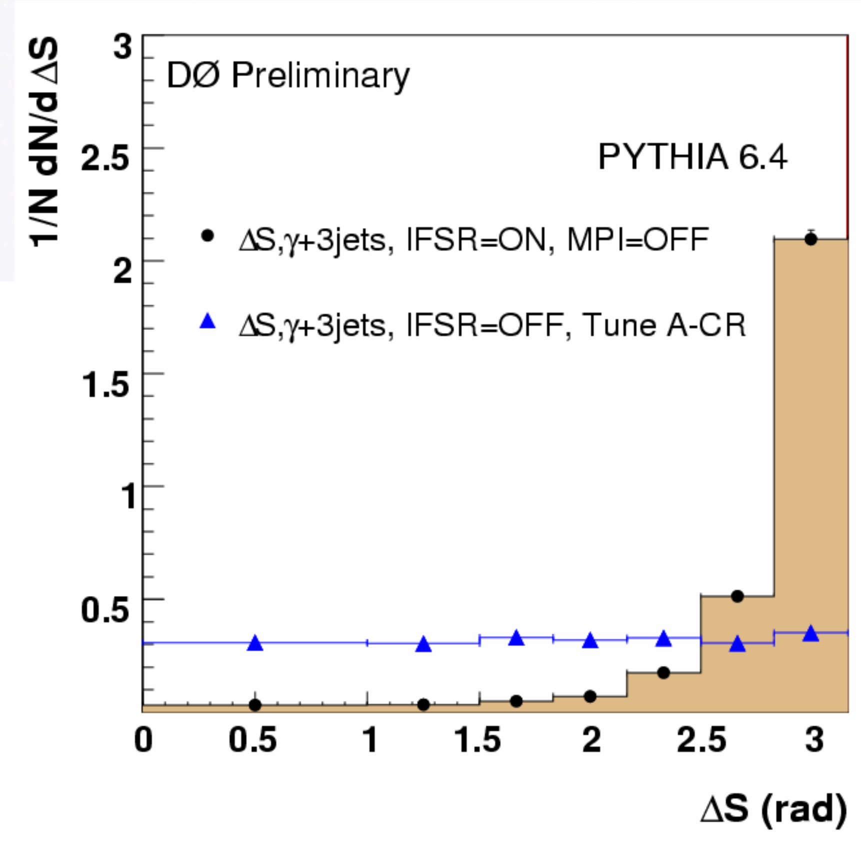
Double Parton Interactions

Look for two hard scatters in same p-pbar interaction

Provides complementary information on proton structure



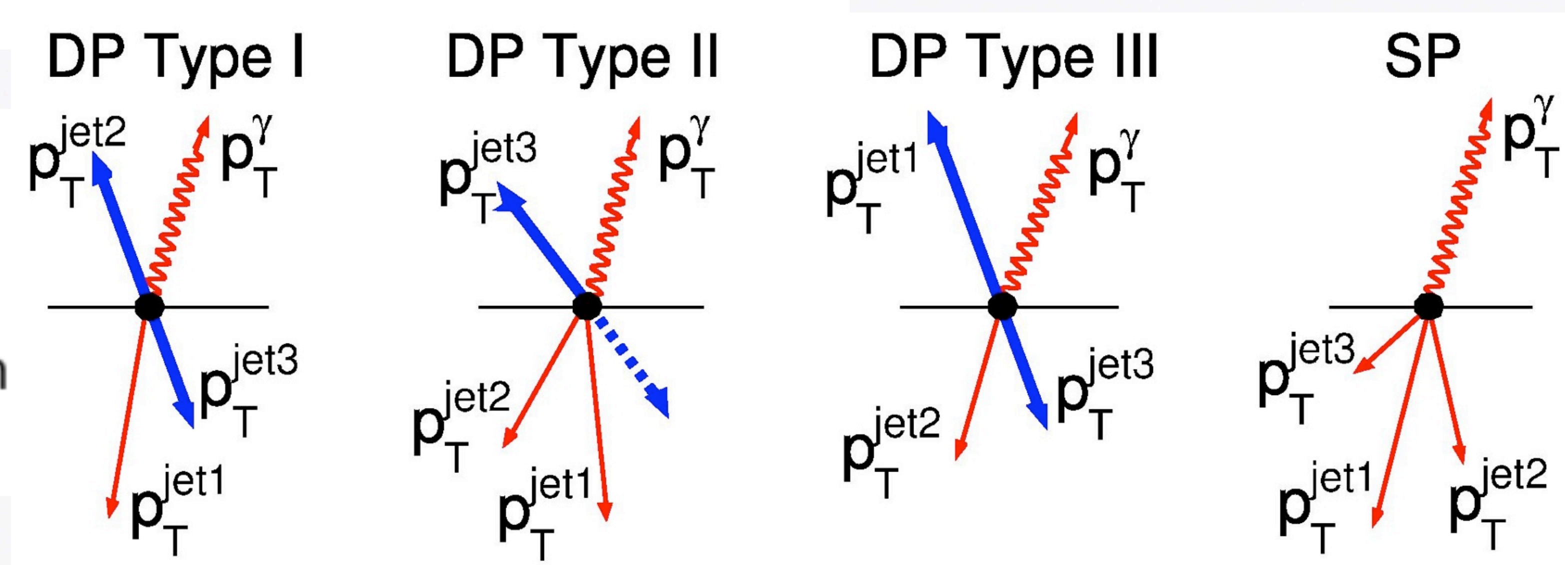




Discriminant:

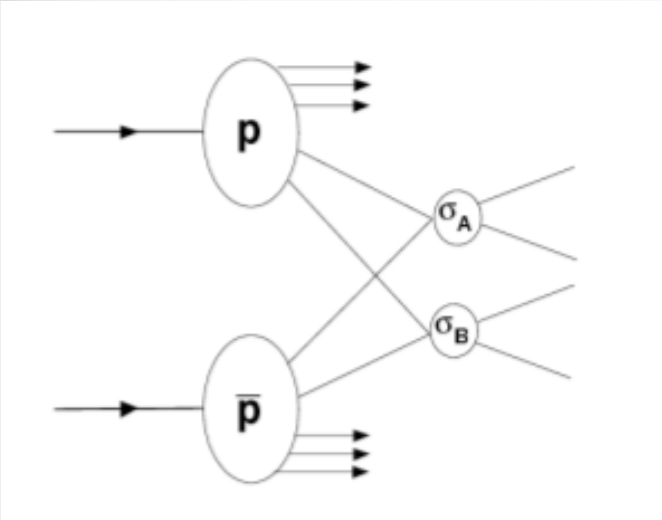
$$\Delta S = \Delta\phi\left(\mathbf{p}_T^{\gamma,jet_i},\ \mathbf{p}_T^{jet_j,jet_k}\right)$$

Δϕ - an azimuthal angle between two best pT-balanced pairs.



dominant background

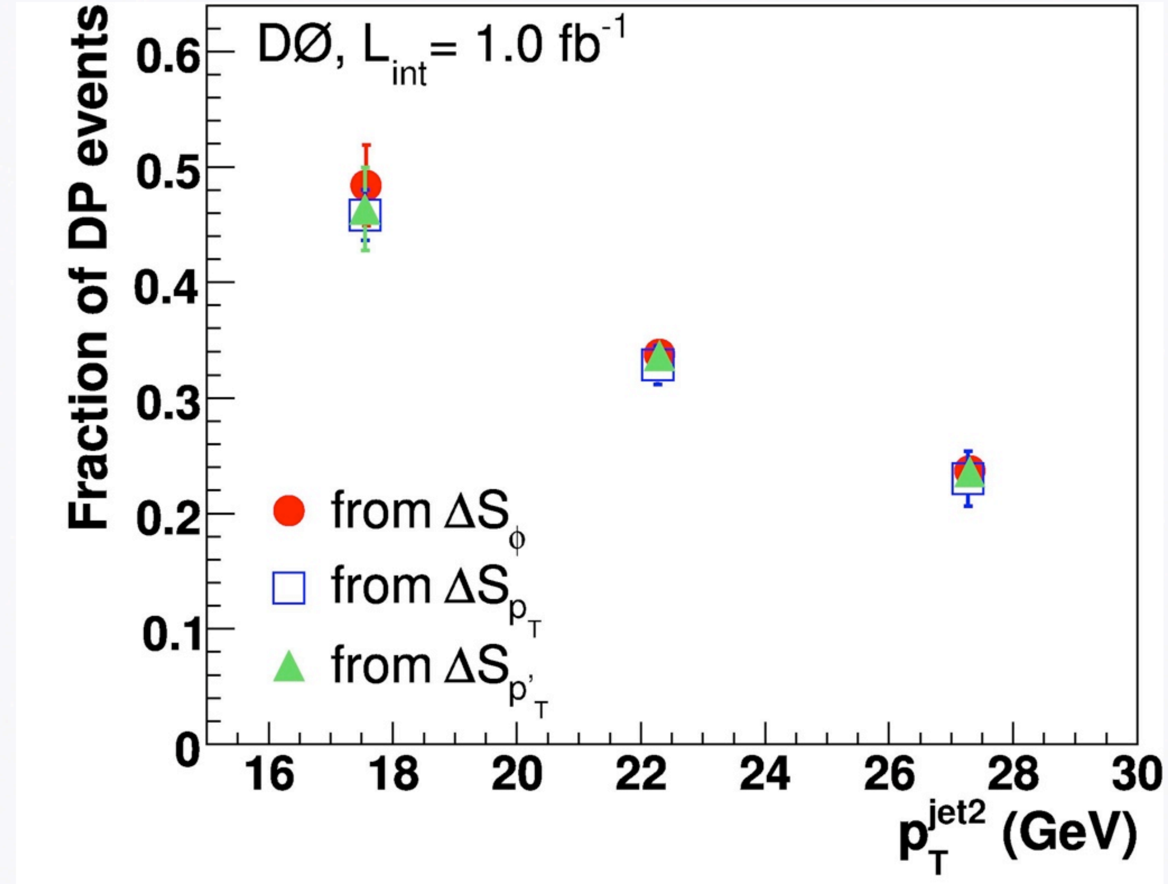
Double Parton Scattering

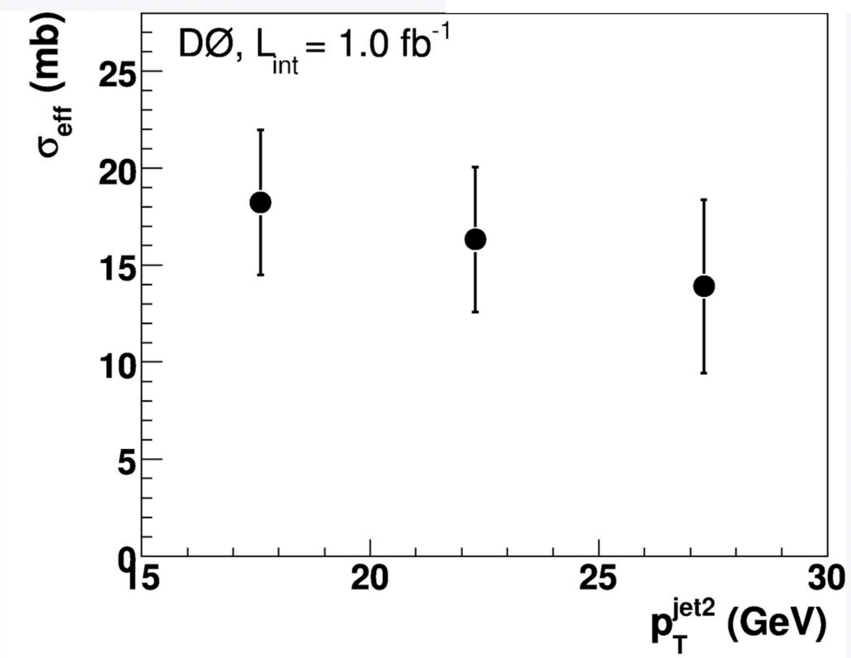


$$\sigma_{DP} = \frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

$$S_\phi = \frac{1}{\sqrt{2}} \sqrt{\left(\frac{\Delta\phi(\gamma,i)}{\delta\phi(\gamma,i)}\right)^2 + \left(\frac{\Delta\phi(j,k)}{\delta\phi(j,k)}\right)^2}$$

$$S_{pT} = \frac{1}{\sqrt{2}} \sqrt{\left(\frac{|\vec{P}_T(\gamma,i)|}{\delta P_T(\gamma,i)}\right)^2 + \left(\frac{|\vec{P}_T(j,k)|}{\delta P_T(j,k)}\right)^2}$$





Effective cross section is approximately constant across p_T bins and in agreement with previous CDF Result

DP Properties in the works:

- unfolding distributions
- triple parton interactions
- parton x correlations
  ➡ provides information for building optimal MPI model

$$\sigma_{eff}^{ave} = 16.4 \pm 0.3(stat) \pm 2.3(syst)\, mb$$

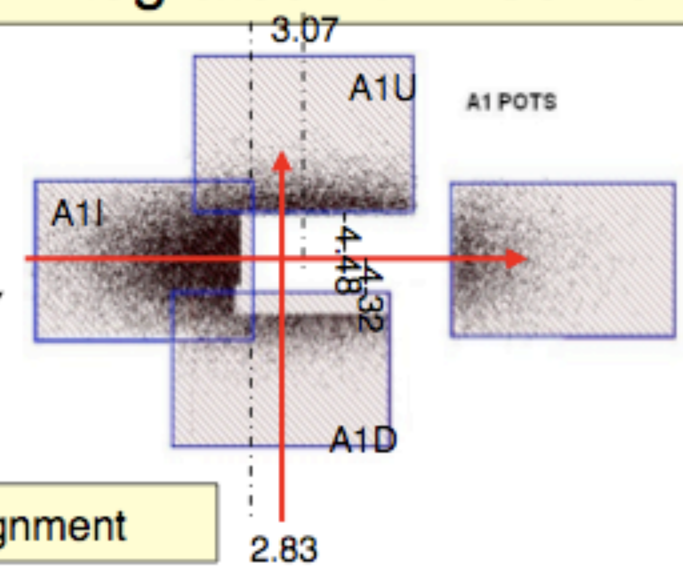
Elastic Cross Section

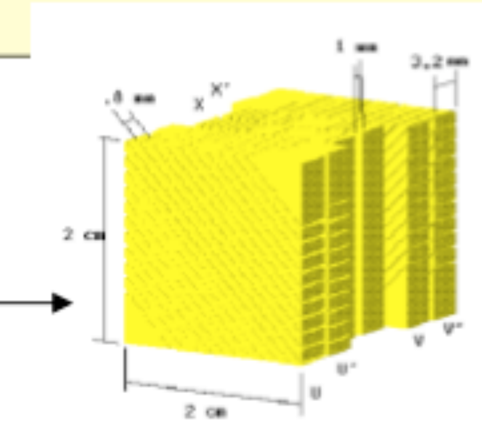
Special store for FPD with β_{D0}=1.6m. Only 1 proton and 1 pbar bunch Colliding. Separators OFF, heavy scraping. Integrated Lum~30 nb^{-1}

Two sets of POT positions:

	Lumi(nb^{-1})
SET 1	18.3
SET2	12.6

Second set: corners of pots overlap →useful for Alignment



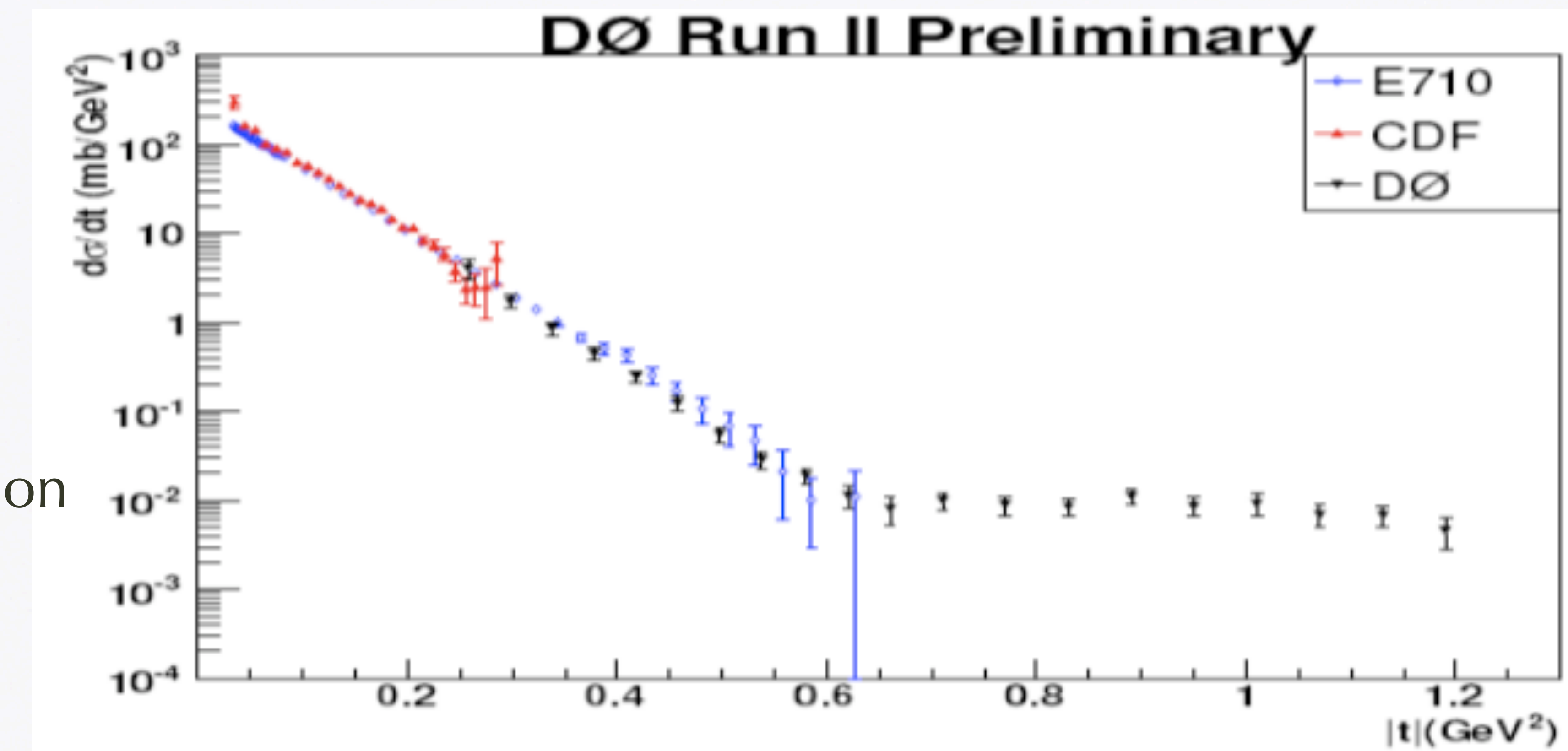


6 layers of scintillating fibers forming 3 planes with different fiber orientation

Huge amount of work:

- dedicated triggers
- FPD efficiencies
- FPD alignment
- acceptances
- halo background estimation
- luminosity determination

result presented at DIS2010



Summary and Conclusion

- QCD measurements and publications are on the rise
  - higher statistics -> measurements become systematics limited
  - we will learn much more, especially in W/Z/γ + heavy flavor by looking at more data
- Precision physics => this has taken us years to achieve
- Our inputs to PDF fits are world class
- W/Z/γ + jets measurements crucial for understanding backgrounds to NP and SM Higgs searches
  - we have some interesting theory discrepancies
- QCD Legacy measurements are being made at D0 now!

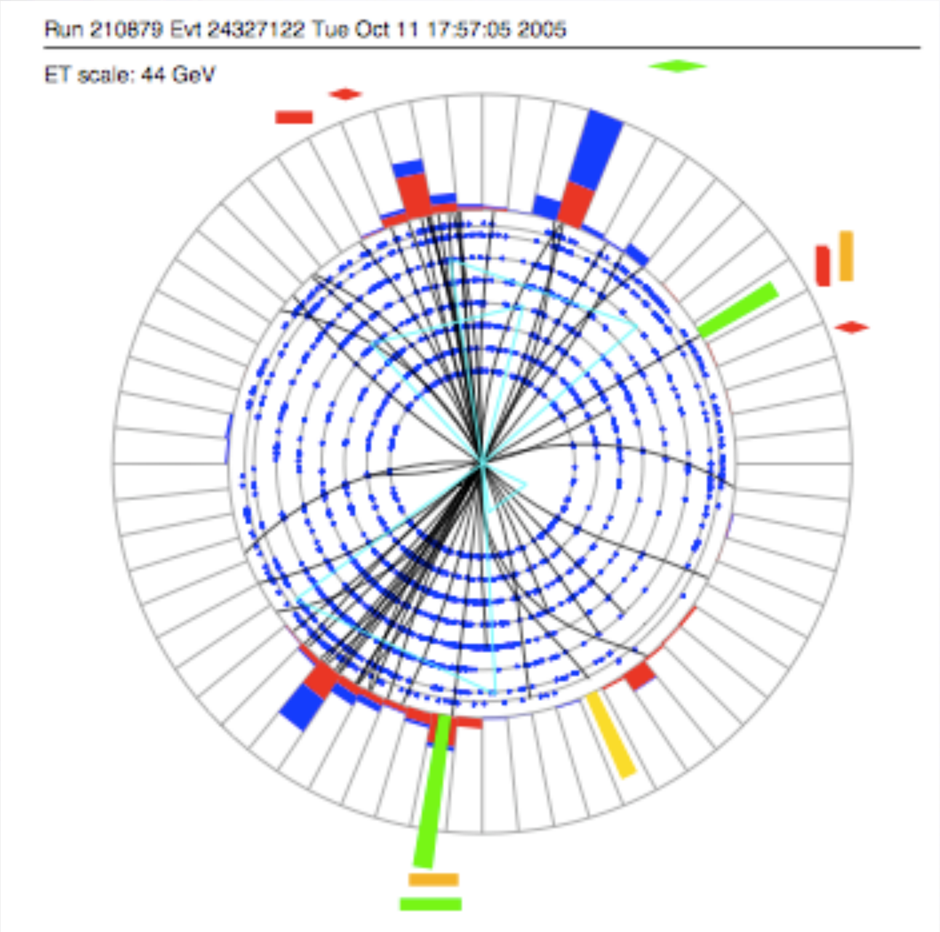
See D0 QCD Public Webpage for details and many more plots

Outlook

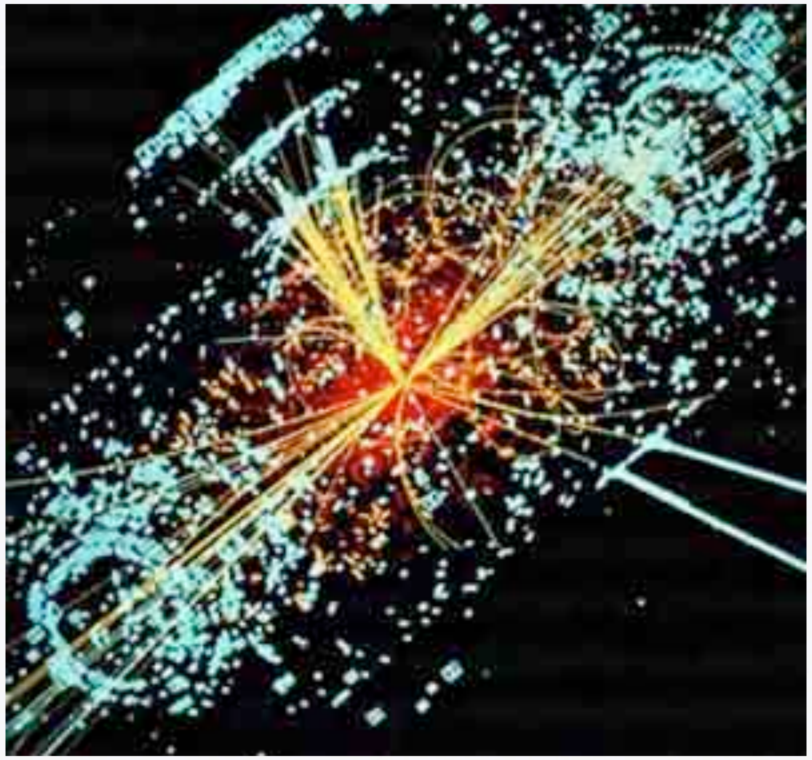
- Tevatron will continue to run through FY2011
  - there will be a 1-month shutdown this summer
- Discussions/Studies for extending the Tevatron run through 2014 are ongoing within the experiments
- QCD Physics with 12 fb^{-1} ?
  - Inclusive Jets at high pT
  - Determinations of α_s from multijet production
  - Dijets: triple differential cross sections are ultimate source of PDF information
  - Dijet χ to search for BSM physics
  - W/Z/γ + b(b) cross sections
  - b-jet energy scale from Z->bb
  - Diphoton cross sections in central, forward region
  - Exclusive production of Z, di-EM states

Final Thought

A concerted effort by experimentalists and theorists is needed to resolve existing puzzles and improve theoretical predictions which are critical for NP searches at both the Tevatron and LHC. Tuning to Tevatron data is a good opportunity.



TeV-->LHC



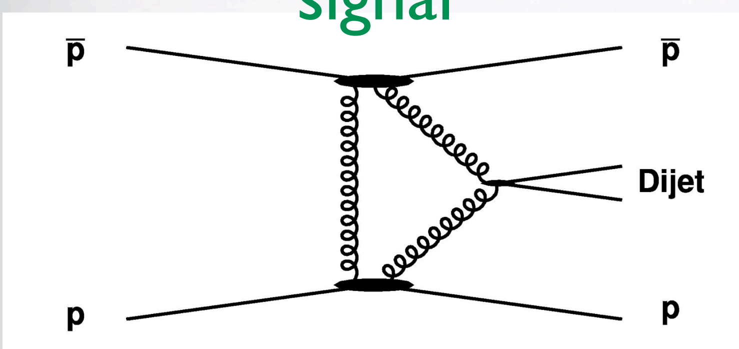
Additional Slides

NLO pQCD calculations & MC Models

- pQCD predictions calculated with MCFM, Rocket, JetPhoX, fastNLO, NLOJET++,...
- Many LO MC programs on the market:
  - MEPS: Alpgen, Sherpa, Madgraph, Helac, Madevent, ...
  - PS: Pythia, Herwig, Ariadne, ...
- CKKW
  - the separation of ME and PS for different multijet processes is achieved through a k_T-measure
  - undesirable jet configurations are rejected through reweighting of the matrix elements with analytical Sudakov form factors and factors due to different scales in α_s
- MLM
  - matching parameters chosen, ME and PS jets matched in each n-parton multiplicity, events vetoed which do not have complete set of matched jets
  - further suppression required to prevent double counting of n and n+1 samples (replaces Sudakov reweighting in CKKW)

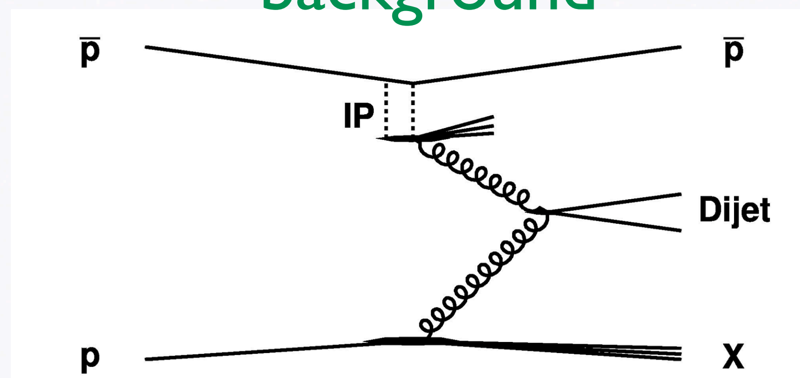
Exclusive Dijet Production

signal



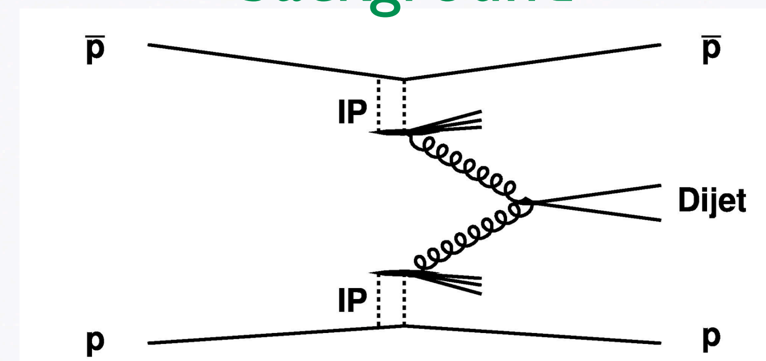
Exclusive diffractive dijet (EDP)

background



Single diffractive (SDS)

background



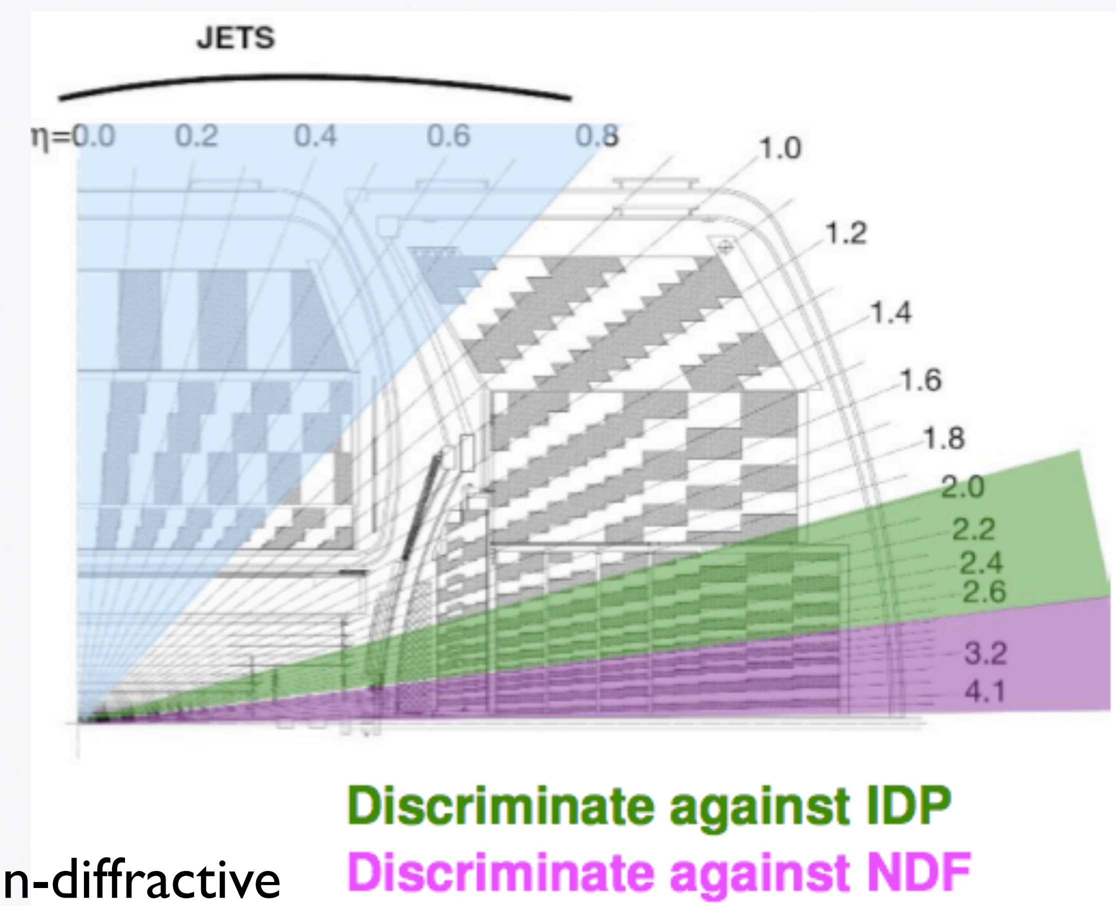
Inclusive double pomeron (IDP)

require 2 central jets,
study forward region

- Study mechanism of EDP production at high dijet mass
- Discriminant: $\Delta=$

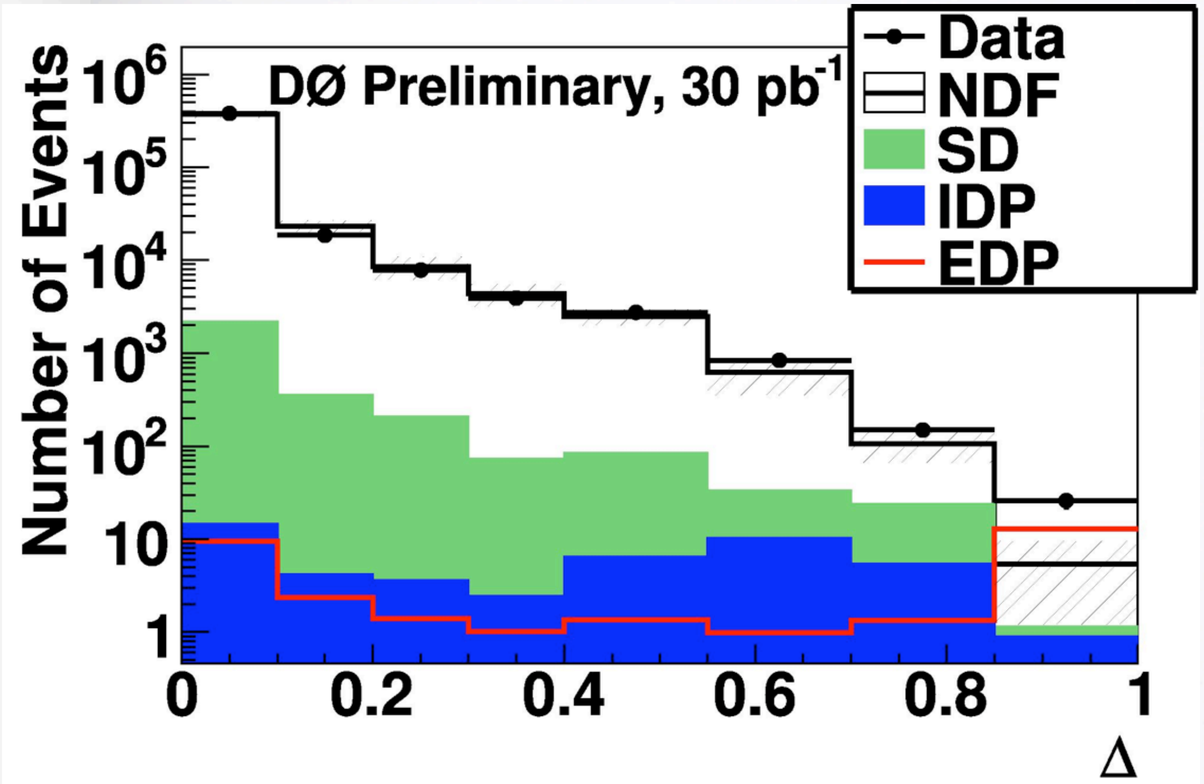
$$\frac{1}{2}\exp\left(-\sum_{20<|ieta|\leq 30} E_T\right)+\frac{1}{2}\exp\left(-\sum_{|ieta|>30} E_T\right)$$

designed to discriminate against different bkgrds simultaneously

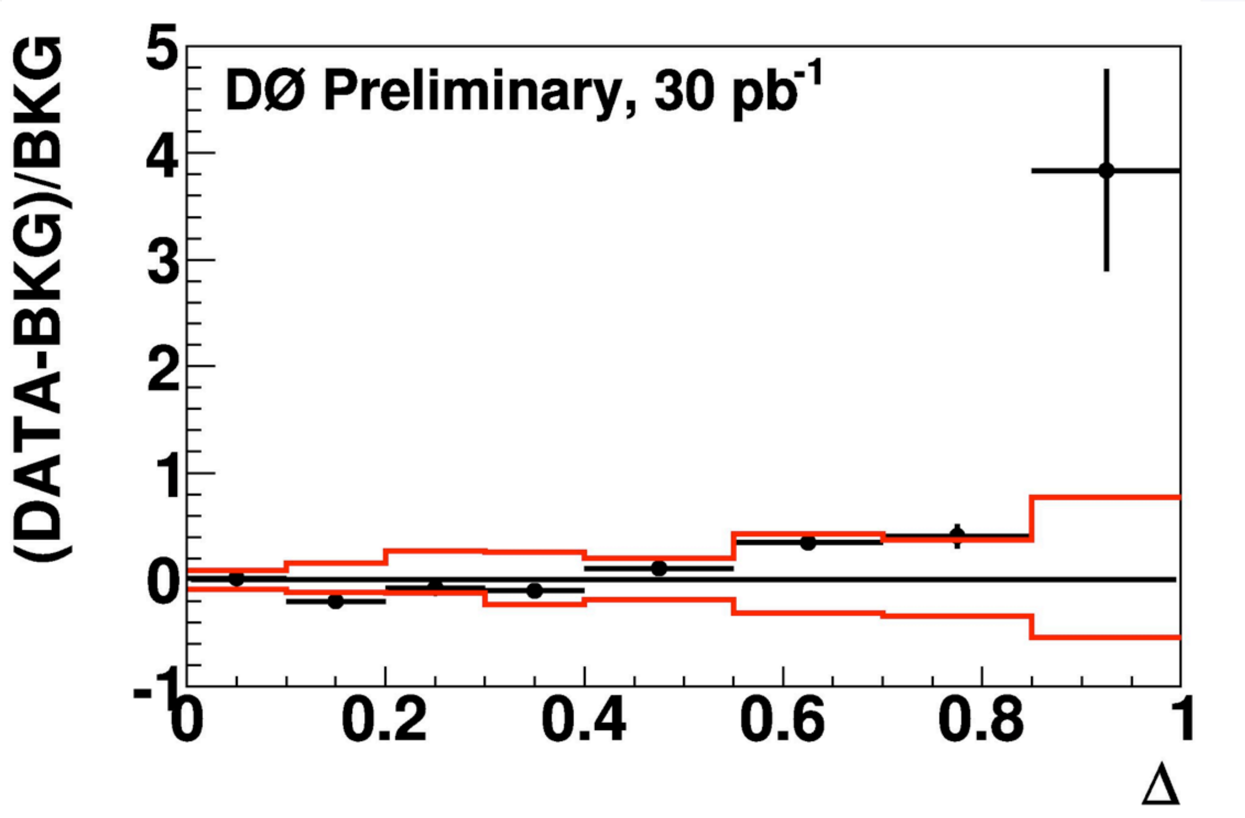


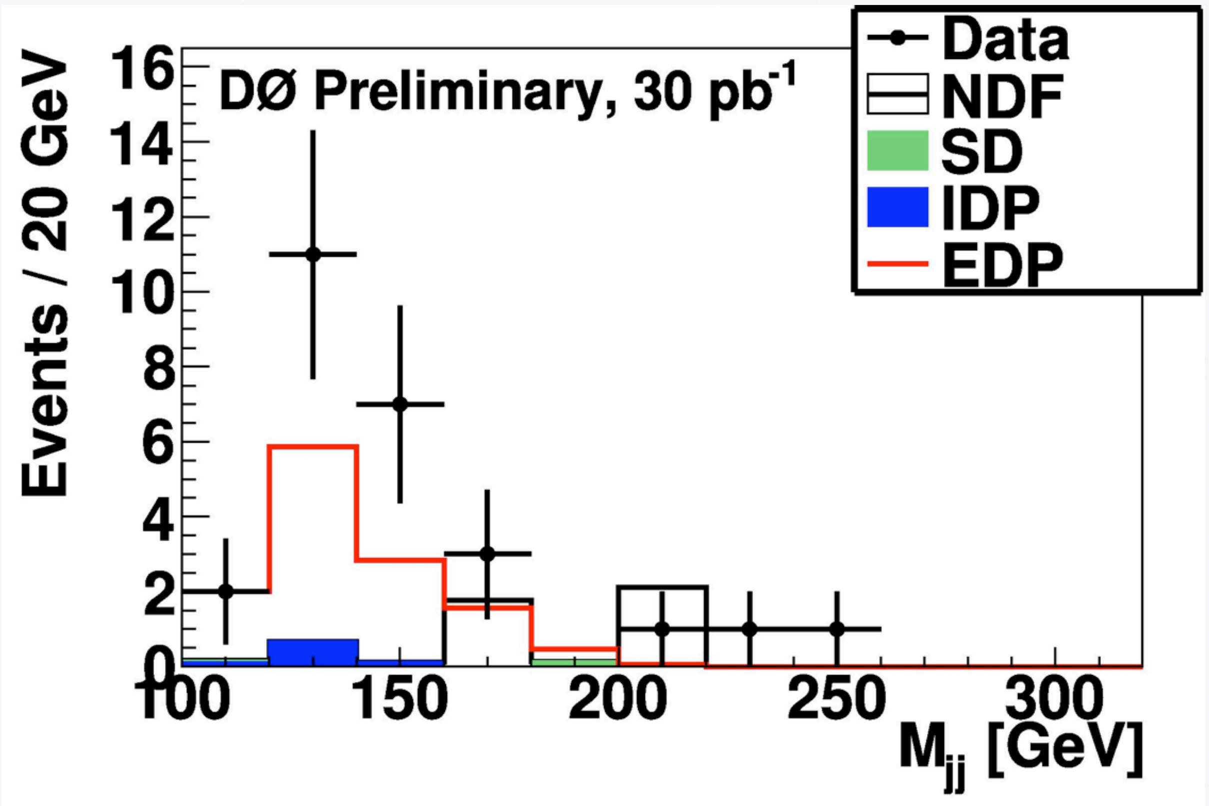
NDF= non-diffractive

Exclusive Dijet Production

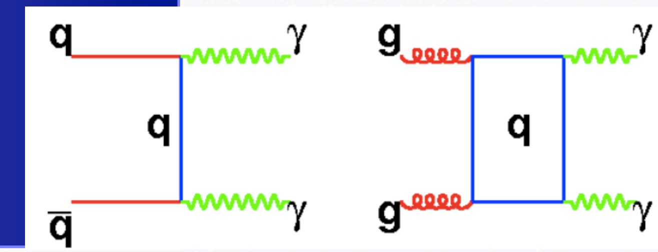


- Discriminant works well
- 26 candidate events in Δ >.85, $5.4^{+4.2}_{-2.9}$ background events
- 4.1σ evidence of EDP

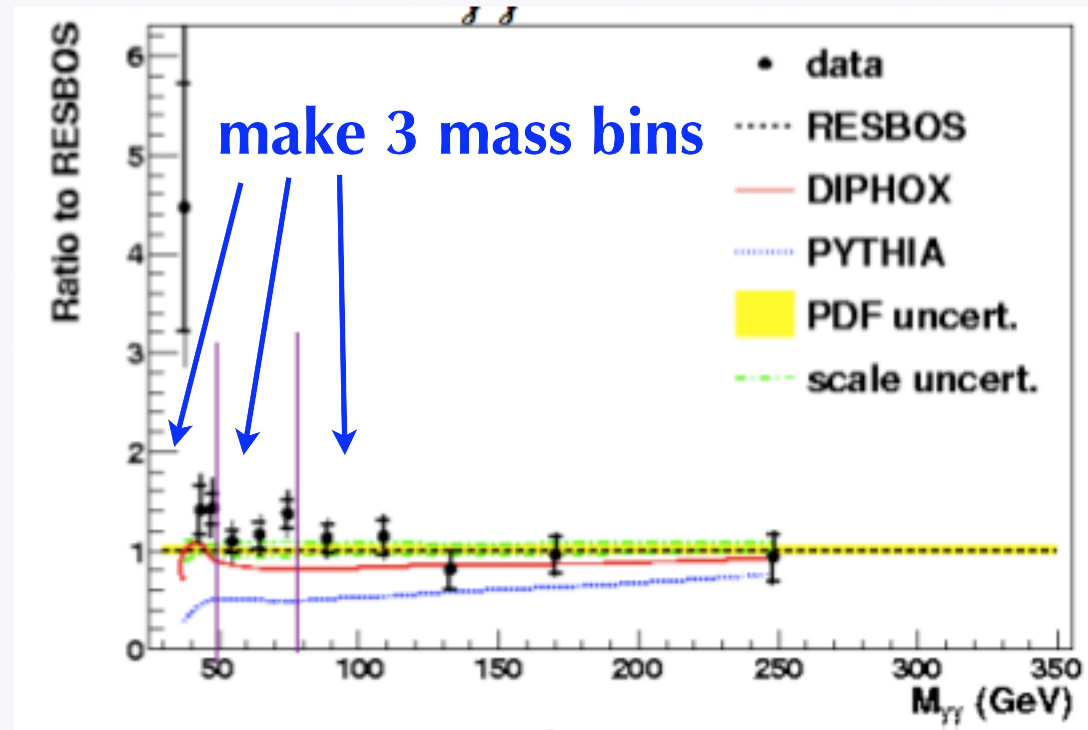


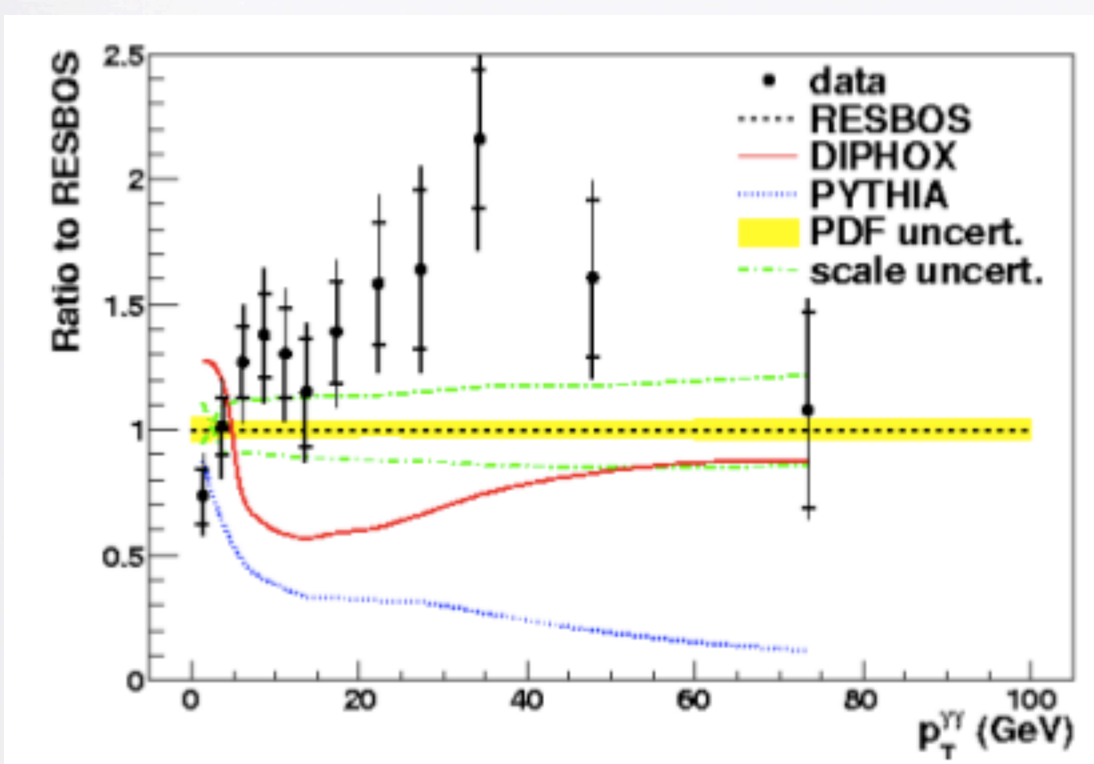


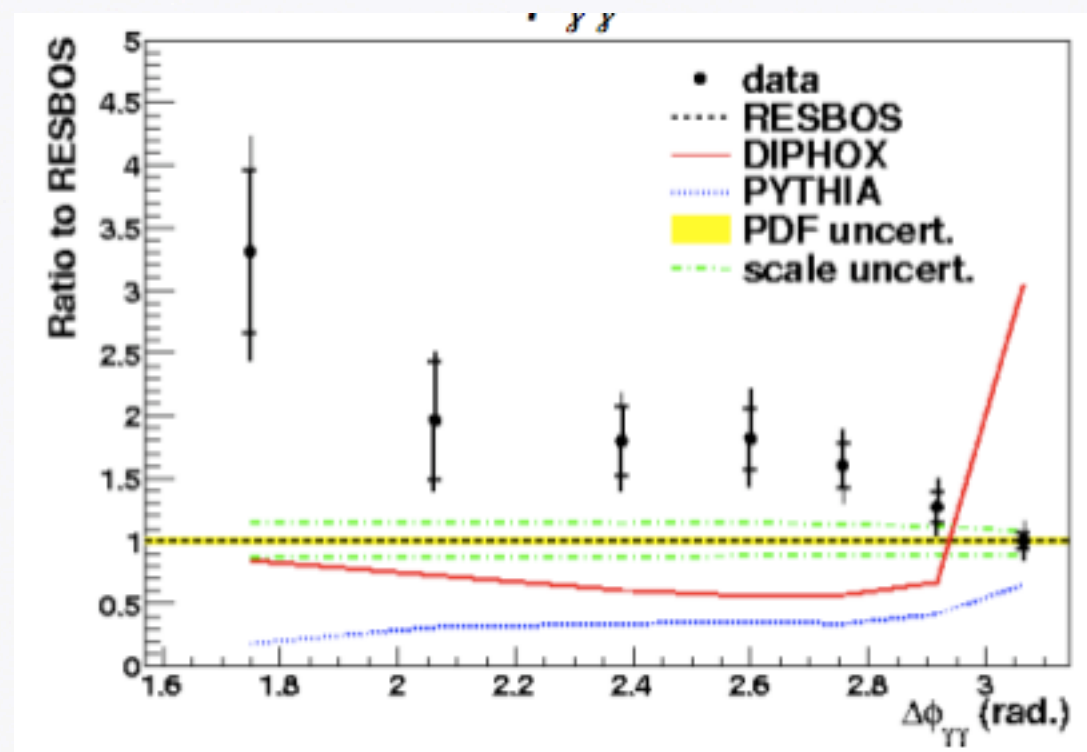
Direct Diphoton



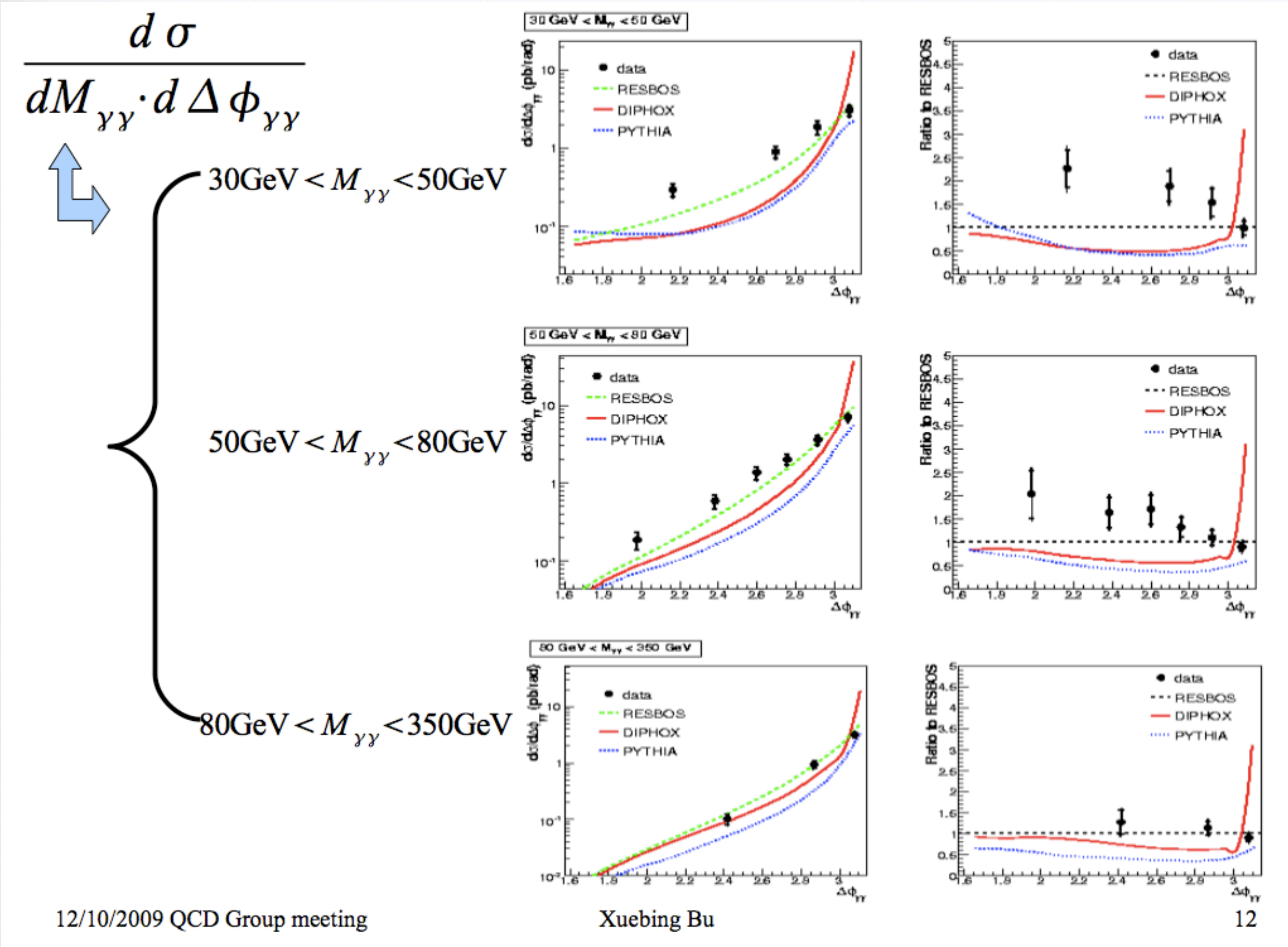
- Major background to H→γγ
- Data corrected to particle level using bin-by-bin unfolding
- Tools from W mass analysis
- Data/Theory discrepancies
    - largest at low mass, where gg contribution dominates



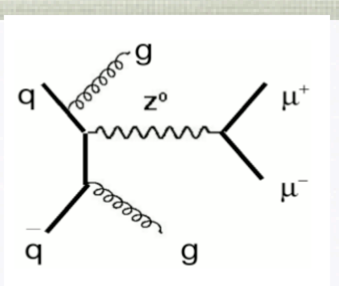




Diphoton - double differential



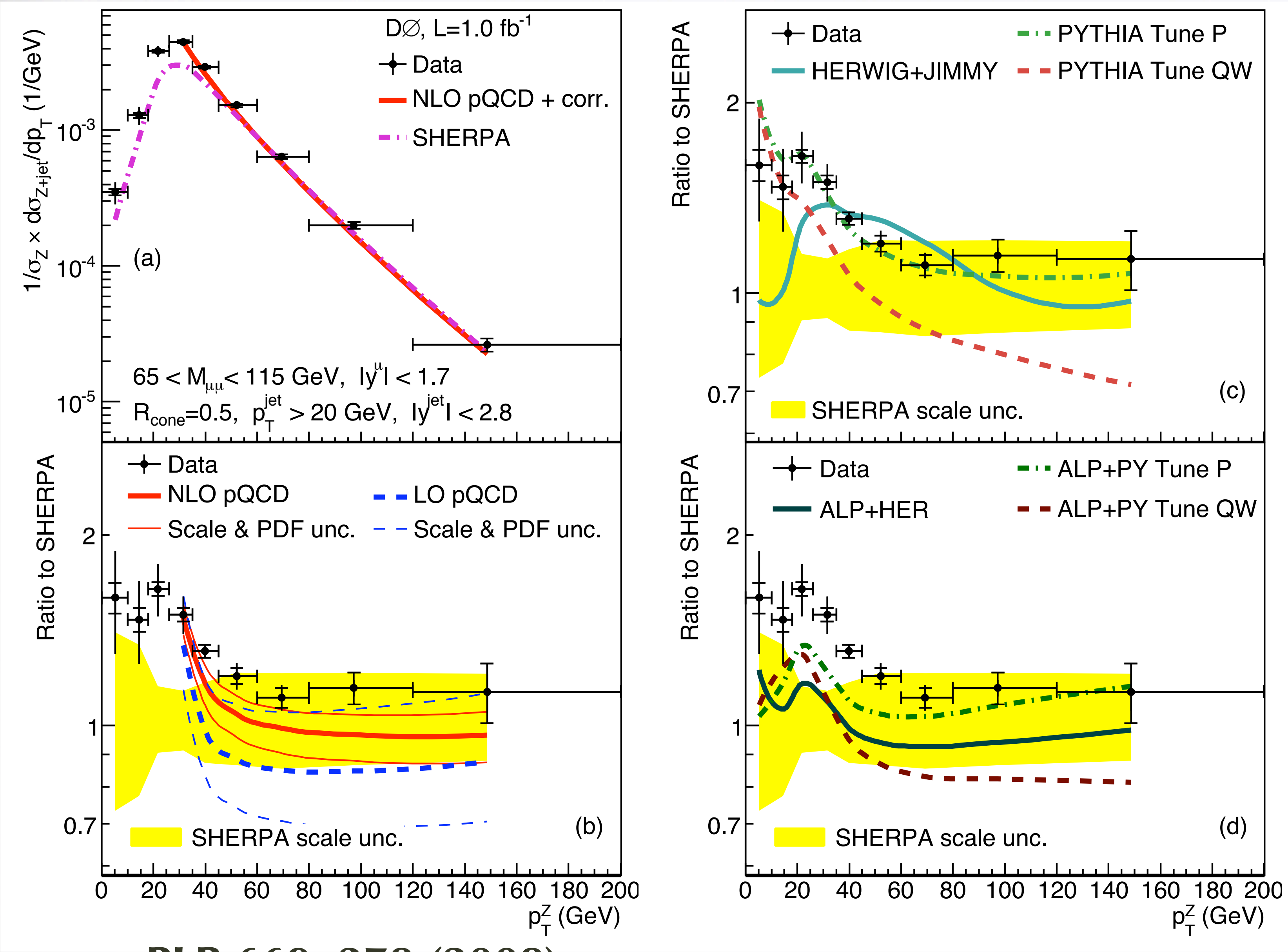
Z->μμ + jet + X - p_T spectra



Particle level phase space:
65 GeV< $M_{\mu\mu}$ < 115 GeV,
D0 midpoint R_{cone}=0.5, p_T^{jet} > 20 GeV
$|y^{jet}|$ < 2.8, $|y^{\mu}|$ < 1.7
muons include QED radiation

theory predictions updated since publication

ratios relative to Sherpa 1.1.3



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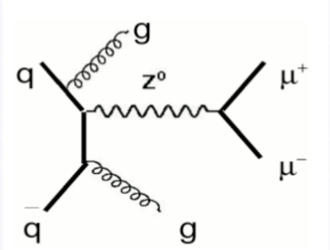
- ✦ NLO prediction with Z p_T<30 GeV sensitive to underlying event
- ✦ All LO predictions underestimate data normalization
- ✦ Pythia can be tuned to reproduce data

All cross sections normalized to inclusive Z production to reduce systematic errors

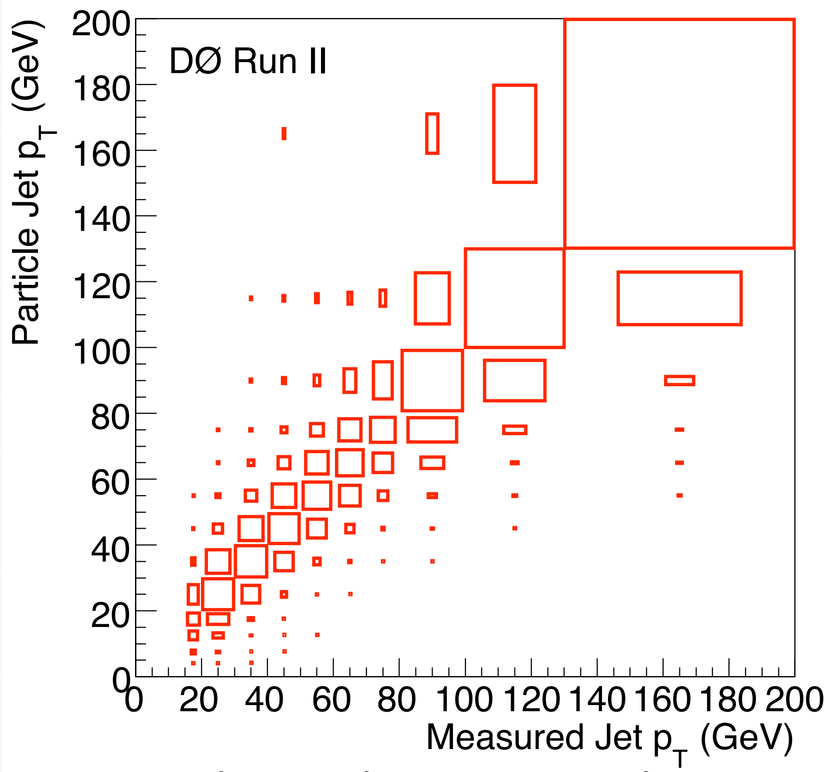
Z->μμ + jet + X - p_T spectra



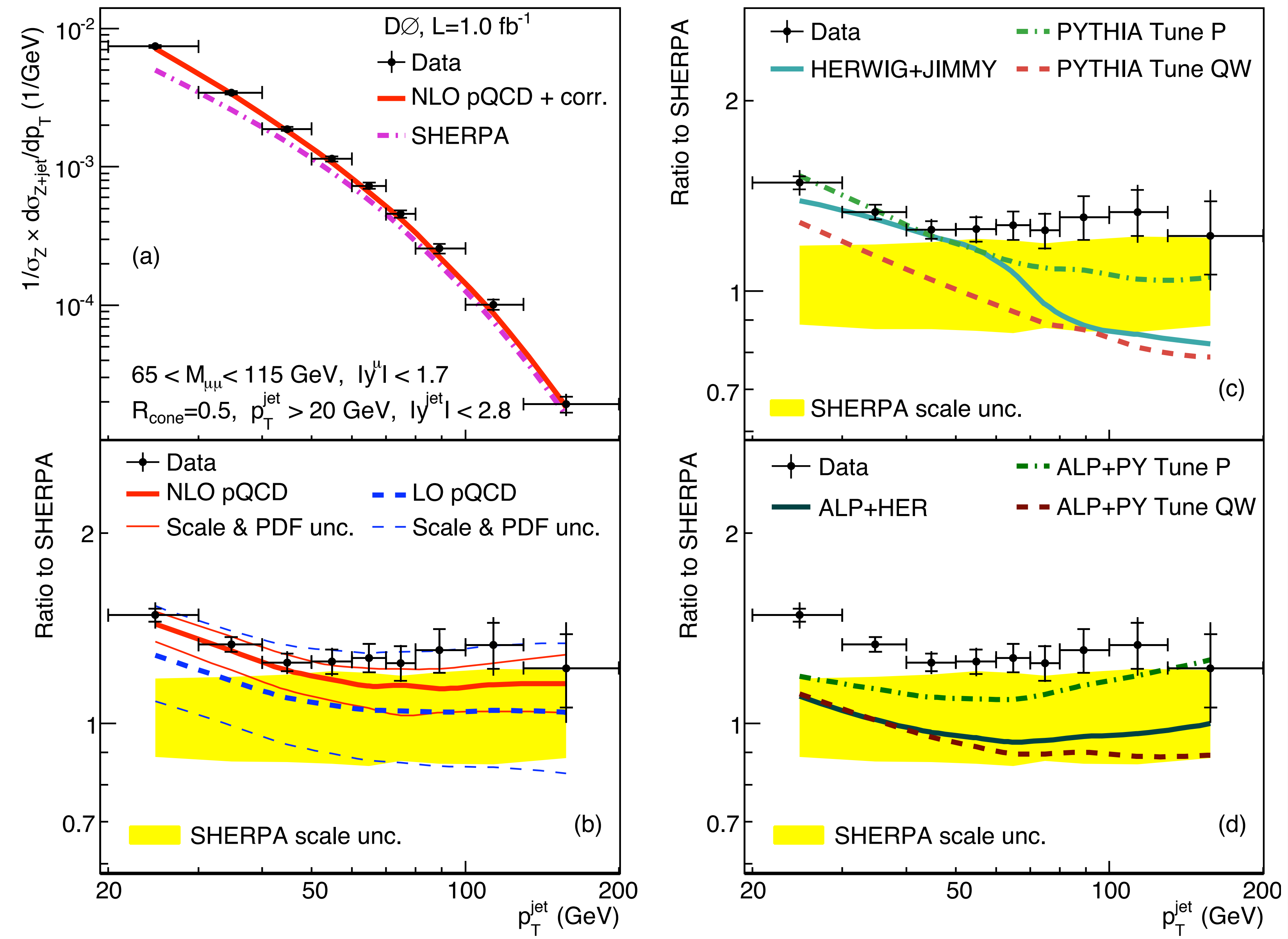
Particle level phase space:
65 GeV< $M_{\mu\mu}$ < 115 GeV,
D0 midpoint R_{cone}=0.5, p_T^{jet} > 20 GeV
$|y^{jet}| < 2.8$, $|y^{\mu}| < 1.7$
muons include QED radiation

theory predictions updated since publication

ratios relative to Sherpa 1.1.3



migration matrix
-> used to unfold data
large migrations,
especially at low p_T



MCFM v5.4 PDF: MSTW2008
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$

PYTHIA v6.420
Pythia Tune P
Pythia Tune QW
HERWIG v6.510 + JIMMY v4.31
ALPGEN v2.13+PYTHIA v6.420
ALPGEN v2.13+HERWIG v6.510

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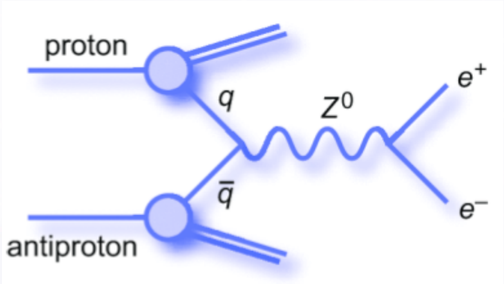
Z->ee + jet + X - p_T spectra

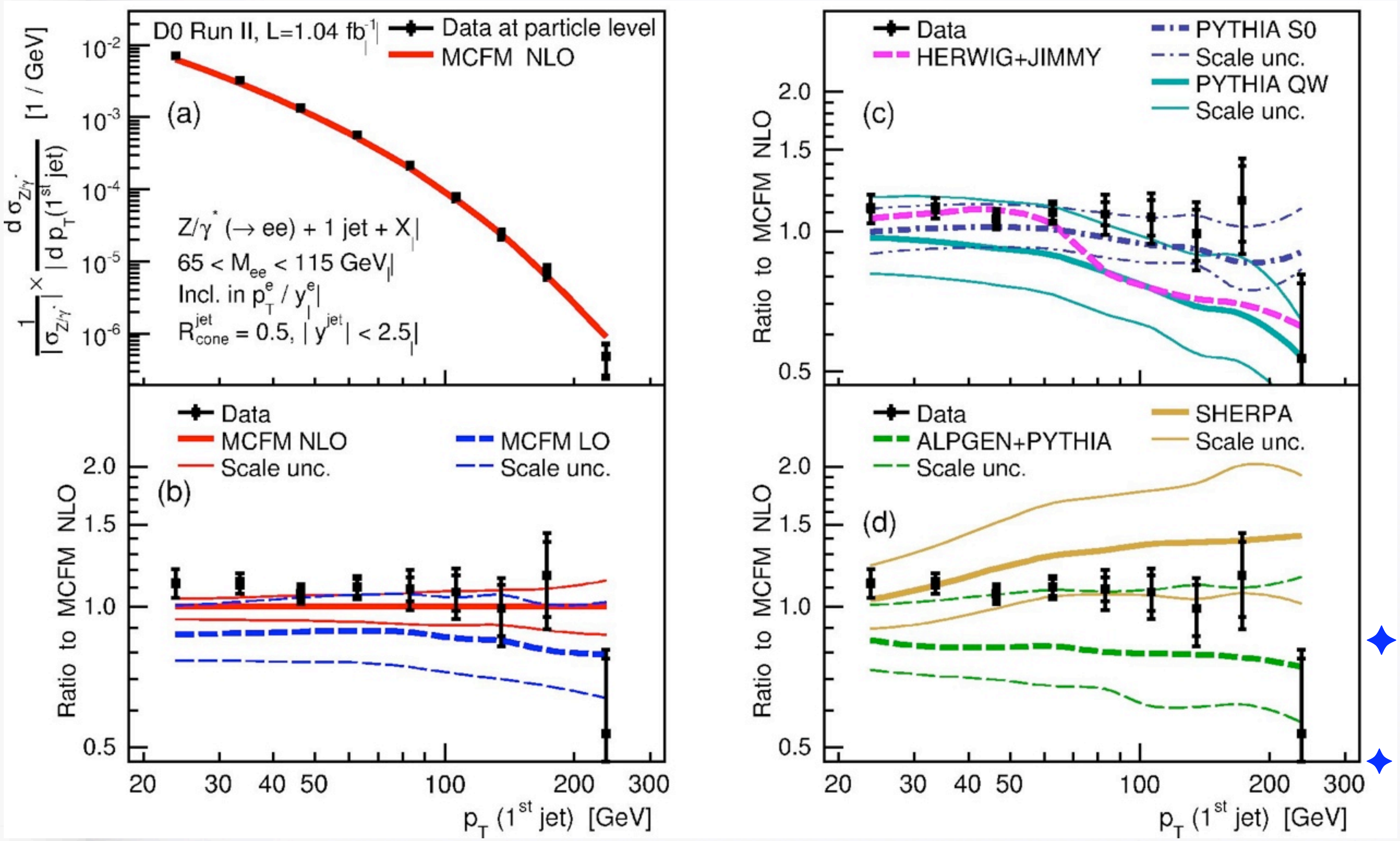


Particle level phase space:
65 GeV< M_{ee} < 115 GeV,
D0 midpoint R_{cone}=0.5, p_T^{jet} > 20 GeV
$|y^{jet}|$ < 2.5, Incl in $p_T^e/|y^e|$

normalized to
inclusive Z production

**ratios relative to
MCFM NLO**

MCFM v5.3 PDF: CTEQ6.6M
$\mu_r^2 = \mu_f^2 = p_{T,Z}^2 + M_Z^2$



PYTHIA v6.416
Pythia Tune SO
Pythia Tune QW
HERWIG v6.510
+JIMMY v4.31

ALPGEN v2.13
+PYTHIA v6.325
SHERPA v1.1.1

- ✦ Large differences between models
- ✦ Small experimental errors

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W+c jets

Sensitive to s-quark PDF

$\mathcal{L}$ = 1.8/fb

$$\sigma_{Wc} \times \mathrm{BR}(W \to \ell\nu) = \frac{N^{OS-SS}_{\mathrm{tot}} - N^{OS-SS}_{\mathrm{bkg}}}{Acc \cdot \int L\,\mathrm{dt}}$$

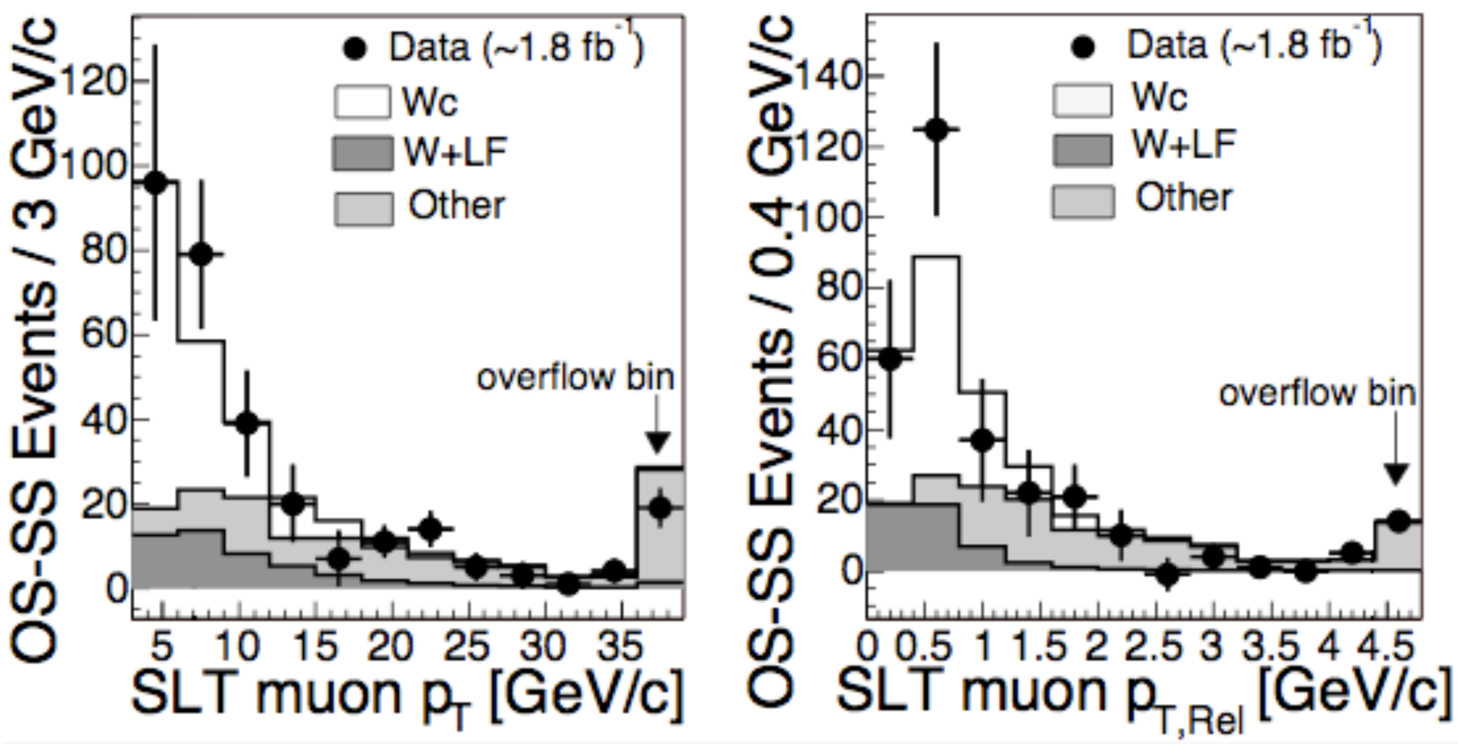
NLO prediction: 11.0 pb

Result:

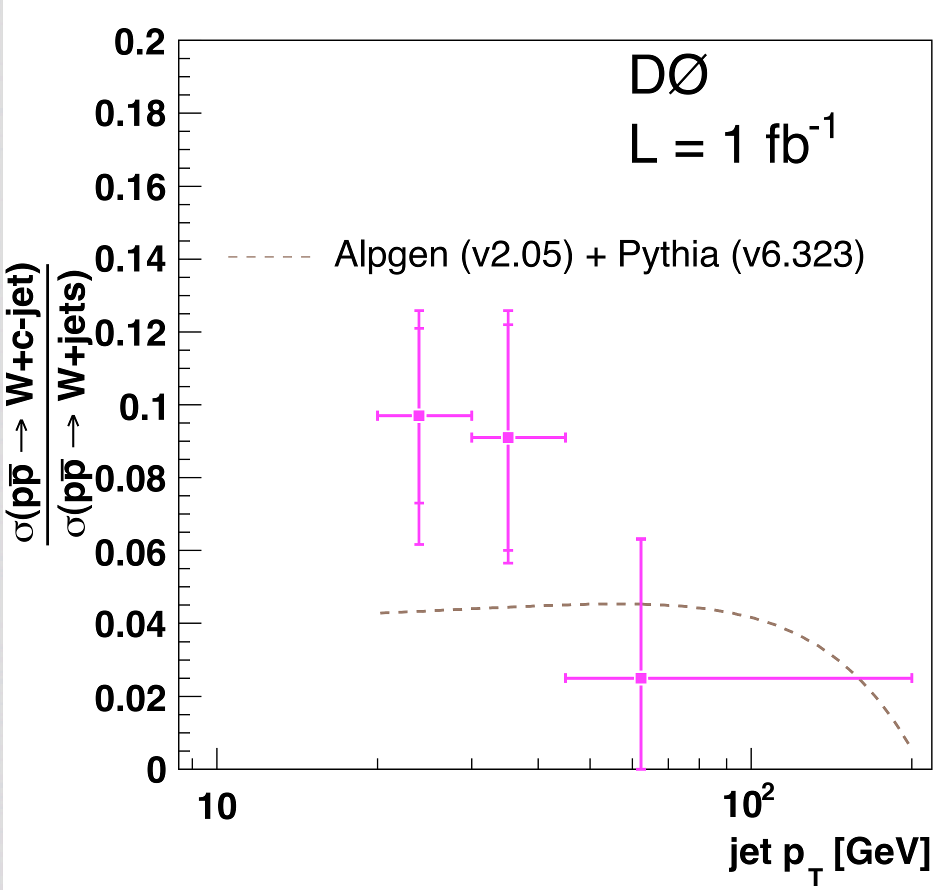
measure σ(W+cjets)xBR(W->lν)

$= 9.8 \pm 2.8$ (stat)$^{+1.4}_{-1.6}$ (sys)

+ 0.6(lumi) pb.



Phys. Rev. Lett. 100, 091803 (2008) , arXiv.org:0711.2901



$\mathcal{L}$ = 1/fb

Alpgen prediction: 0.04 pb

Result: measure σ(W+cjets)/σ(W+jets)

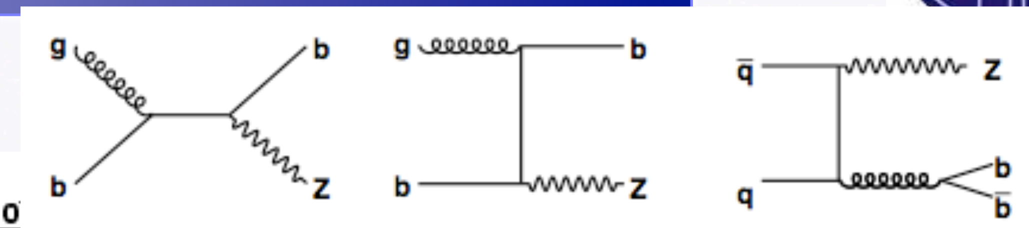
$= 0.074 \pm 0.019$ (stat) $\pm\ ^{+0.012}_{-0.014}$ (sys)

Phys.Lett.B666:23-30 (2008), arXiv.org:0803.2259

Z+b jets

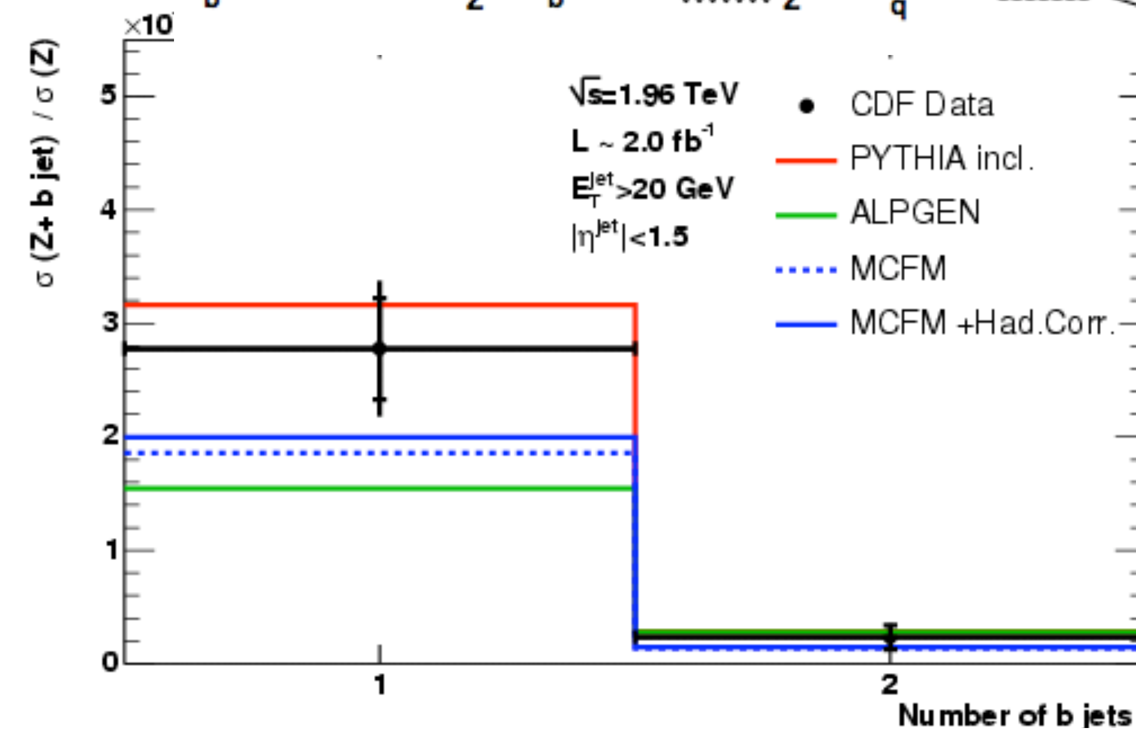
$Z \rightarrow ee/\mu\mu + b + X$
jet $E_T > 20$ GeV, R=0.7
jet $|\eta| < 1.5$
secondary vertex tagging

$\mathcal{L} = 2/\mathrm{fb}$



Measure:

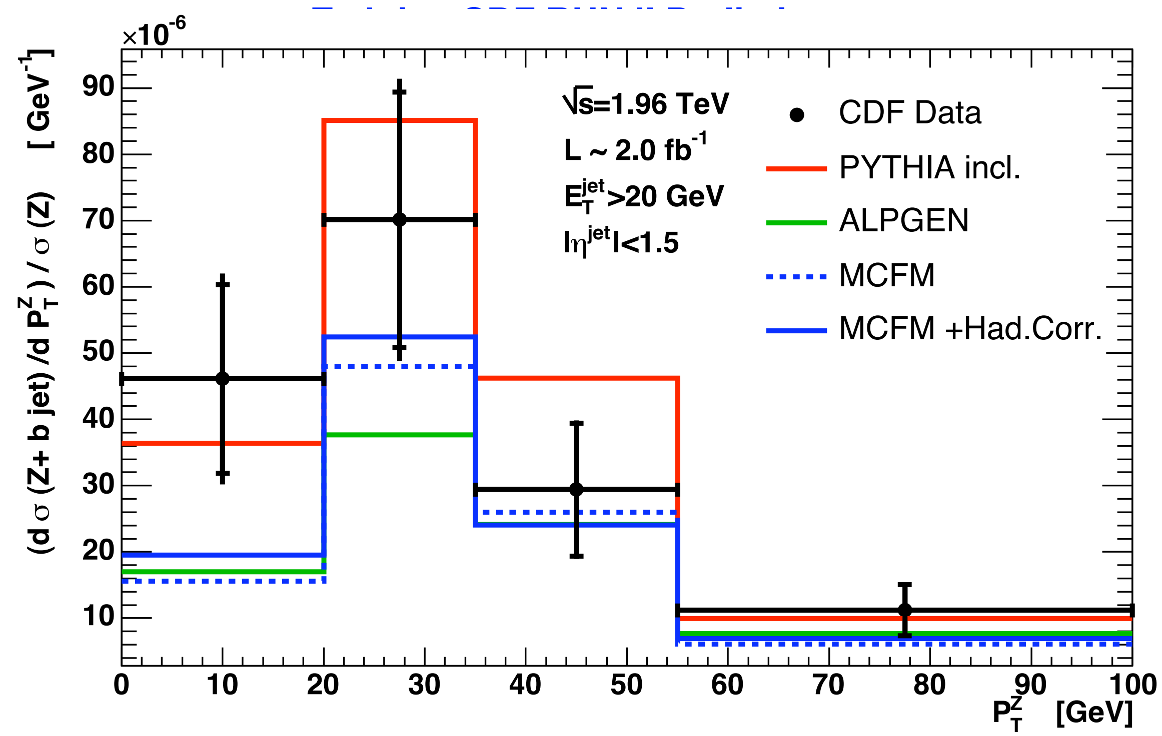
$$\frac{\sigma(Z+b\ \mathrm{jets})}{\sigma(Z)} = 3.32 \pm 0.53(\mathrm{stat}) \pm 0.42(\mathrm{sys}) \times 10^{-3}$$



b,c quark fractions determined from likelihood fit to secondary vertex mass

Pythia can describe overall shape, normalization

Up to 2σ differences between data & MCFM



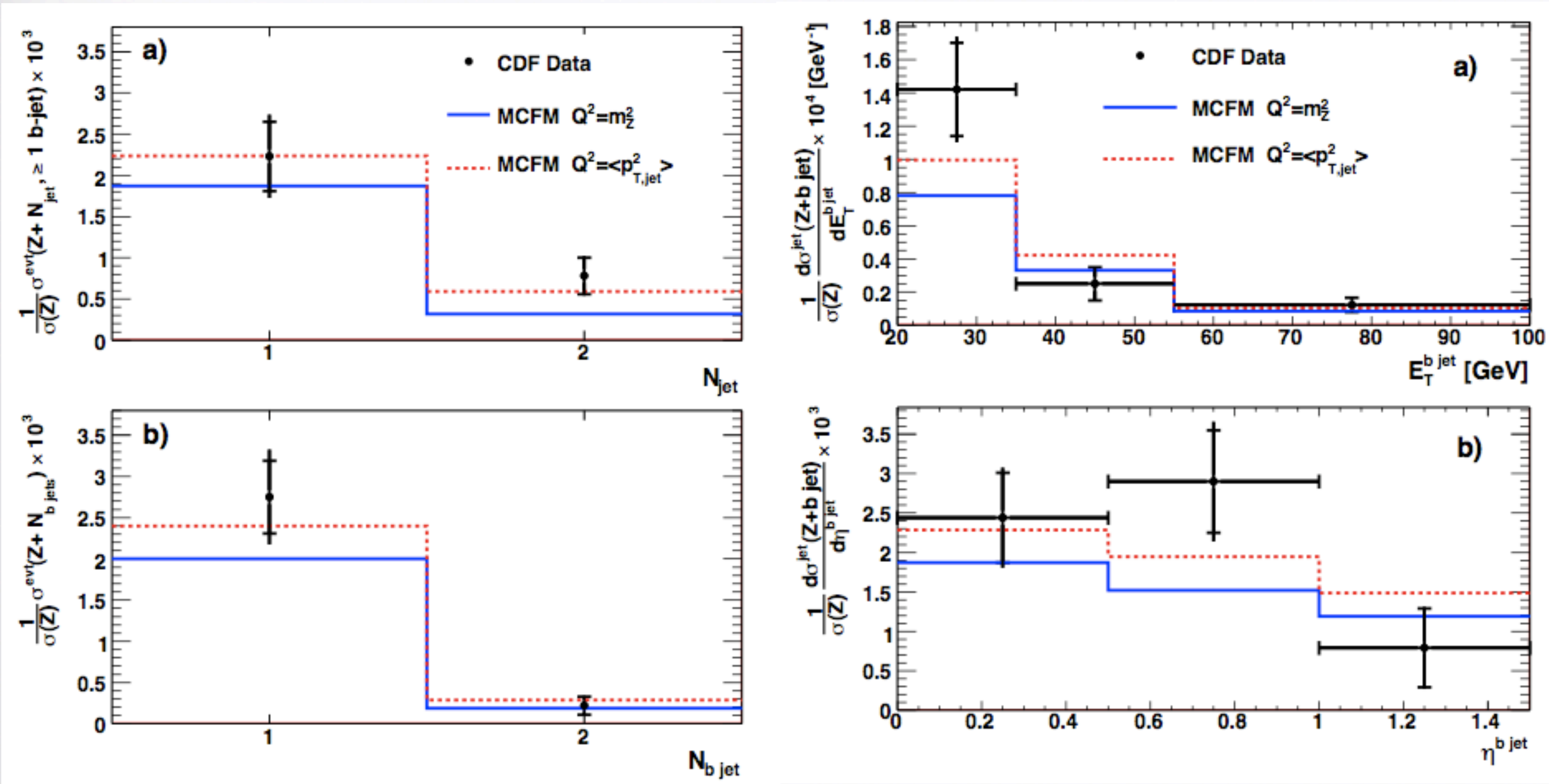
PYTHIA v6.2
- Tune A, CTEQ5L
ALPGEN v2.13

b-quark fragmentation may need study

Phys.Rev.D79:052008, arXiv.org:0812.4458

Z+b jets

MCFM Scale variations



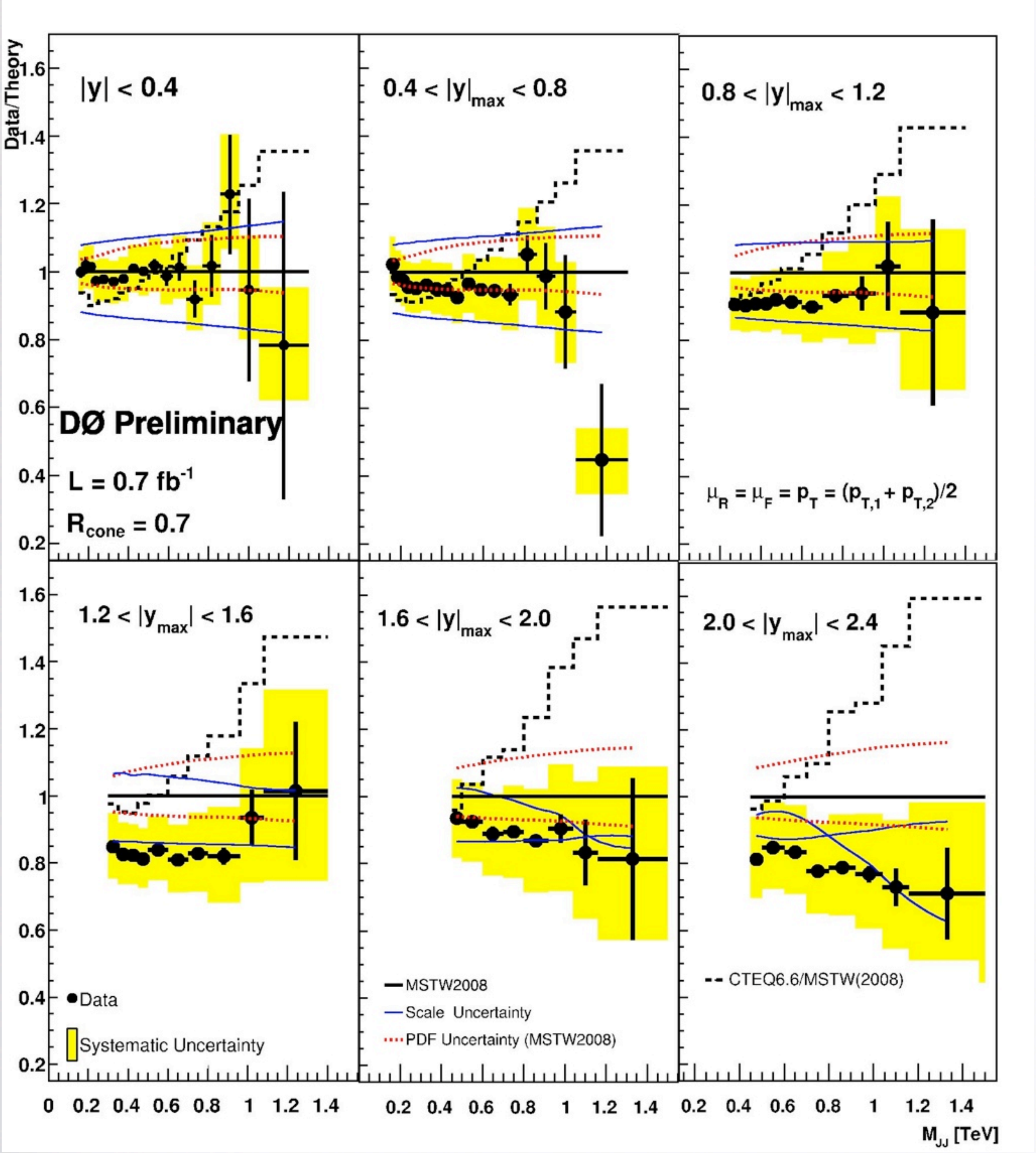
Lowering scale choice helps to describe data

Higher order corrections may be important

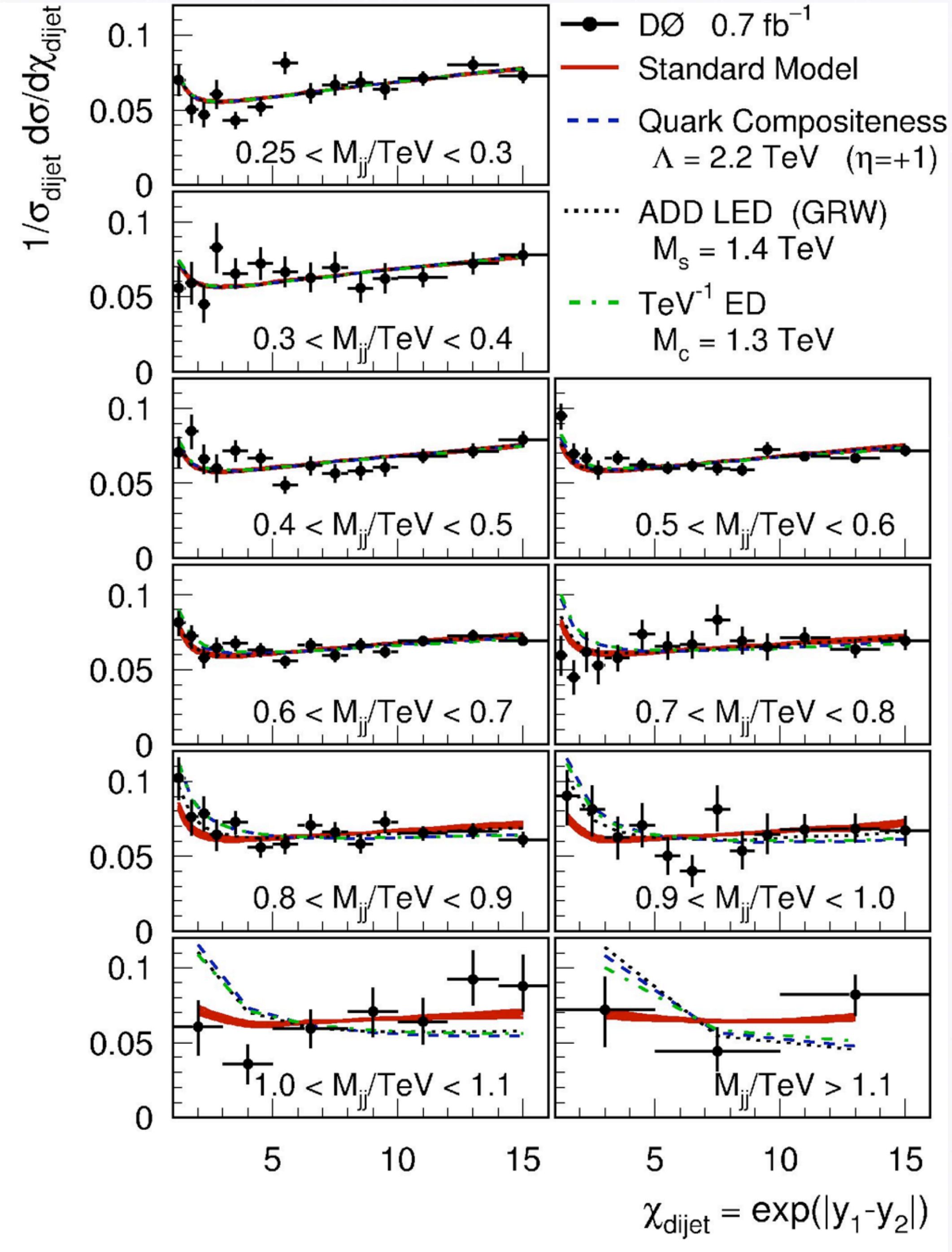
Z+b/Z+jet ratio consistent with D0

Dijets

Dijet mass cross sections binned in rapidity



Dijet Chi cross sections binned in mass



Measure... ... and Search